# Deploying Solar Microgrids in Malawi:

## Lessons Learned and Implications for the Malawian Microgrid Ecosystem

EASE Technical Report


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Rural Energy Access through Social Enterprise and Decentralisation (EASE)

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# Contents

# 1 Background

Lack of access to energy, or insufficient, unreliable energy supplies act as a significant constraint to economic growth and improvement of livelihoods, a significant problem for Malawi where just 18% of the population have access to electricity (11.4% on-grid, 6.6% off-grid) [1] [2]. With cost decreases in solar PV components and Malawi's abundant solar resource, the establishment of solar PV microgrids is being explored, especially in regions unlikely to get a main grid connection imminently [3]. Solar microgrids are estimated to be the lowest cost energy access route for 37% of the population [4], however effective and sustainable business models that are financially feasible while at the same time meeting the social development objectives of the rural communities they serve are needed to implement solar microgrids at scale.

The Rural Energy Access through Social Enterprise and Decentralisation (EASE) project [5] focuses on SDG7 progress in Malawi, running from October 2018 to March 2023 with £1.3m funding from Scottish Government. A project coordinated by the University of Strathclyde (UoS) with partners United Purpose Malawi (UP), Community Energy Malawi and WASHTED, EASE aims to increase access to sustainable energy for rural communities in Dedza and Balaka, enabling economic development and improved livelihoods.

Through EASE, two solar microgrids have been installed in the rural villages of Mthembanji and Kudembe in Dedza district, generating and distributing power for domestic and productive customers. The systems are owned and managed by UP through a social enterprise framework, with technical support and research activities provided by UoS. Detailed monitoring and evaluation and analysis of microgrid performance is being carried out by UoS to inform the Malawian microgrid sector. The motivation for the project is to pilot and demonstrate a social enterprise ownership model for solar microgrids in Malawi, with aims to use this project as a platform to set up further microgrids at other identified sites across Malawi.

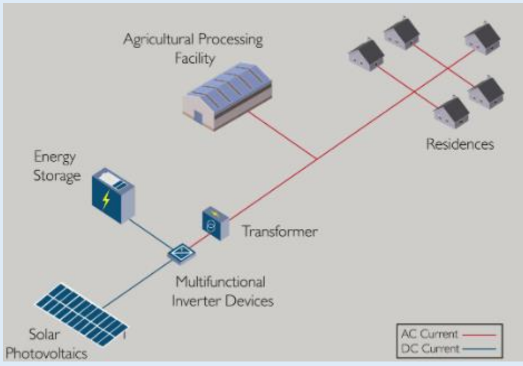
Since it's installation the microgrid at Mthembanji has been collecting valuable data on technical, economic and social impact performance through smart meters, remote monitoring and enumerator surveys. The data allows for monitoring and evaluation to understand microgrid performance, ultimately informing business strategies for the scaling of microgrid operations in Malawi. This operational data has been combined with project management documentation and informal interviews with project developers and field staff, to draw out, document and share key lessons from microgrid implementation, with an aim to increase efficiency, speed and reduce future installation costs.

The purpose of this policy brief is therefore to highlight lessons learned through the firsthand experience of microgrid deployment and operation. Following an overview of the solar microgrids installed through EASE along with the development process, key findings are presented under themes of installation experiences, technical operations, business models and financials, community engagement and social impact. A summary of key recommendations for Malawi's microgrid ecosystem then follows, finishing with next steps for the microgrids and scaling through a social enterprise approach.

### Microgrid definitions and motivations

A nanogrid, microgrid or minigrid is a term used to describe a network consisting of a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the main grid [18]. These terms describe a system that links together demand points within a limited area without connection to the main grid, for the user an experience that is something in between a main grid experience and a standalone experience in terms of quality and quantity of power.

Microgrids (<50kW generation capacity) are intended to offer a new method of rural electrification that allows for more electricity and higher impact than solar home systems currently offered, but cheaper, quicker to implement and potentially more financially sustainable than larger capacity minigrids previously deployed in Malawi.



# 2 Overview of EASE solar microgrids and development process

The microgrids installed in Mthembanji and Kudembe provide wired connections to customers for domestic and commercial use including lights, phone charging, TVs, fridges and other productive uses. Both systems have central generation systems with solar PV panels, Lithium-ion battery storage and power electronics housed in a shipping container. Electricity from the generation hub is distributed through overhead wires on wooden poles to customer premises. The distribution grid is analogous to that of a 240V single phase Low Voltage feeder from a secondary substation on the Malawi ESCOM grid. Smart meters mounted on the distribution poles automatically disconnect customers when their balance runs low, as well as setting power limits to protect the system from misuse.

*Top: Mthembanji, Bottom: Kudembe*

*Figure 1 Summary of key components at the two microgrids*

| | Mthembanji | Kudembe |
|---|---|---|
| **Number of customers** | 60 | 50 |
| **PV Generation** | 11.5 kW | 10.92 |
| **Battery technology** | 48V, Lithium-ion Batteries | |
| **Battery manufacturer** | TESVOLT | BYD |
| **Battery Capacity** | 19.8 kWh | 20 kWh |
| **Inverter manufacturer** | SMA, Germany | |
| **Battery Inverter** | 8 kVA | 8 kVA |
| **PV Inverter** | 10 kVA | 12 kVA |
| **Smart Meters** | Steamaco | |
| **Installation date** | July 2020 | September 2022 |
| **Generation system supplier** | Sustain Solar (South Africa) | BNG Electrical (Lilongwe) |
| **Distribution installer** | BNG Electrical (Lilongwe) | |

The microgrids are operated through field staff employed by UP, with technical support from UoS. UP employ local site agents to act as vendors for electricity sales, site technicians and customer service officers ensuring adequate communication channels between the community and UP. Local site agents also conduct preventative maintenance including PV module cleaning and battery care, as well as reporting any technical problems arising. UP employ MERA accredited BNG Electrical as maintenance contractors to conduct quarterly maintenance visits, troubleshoot any problems raised by the site agent, replace failed components and connect new business and domestic customers.

The development process comprised significant community engagement, regulatory approvals, procurement processes, business modelling and tariff setting before installation and commissioning. A summary of the development process is outlined below, with the challenges and successes discussed in more detail section 3.

# Microgrid Development Process

## Stakeholder engagement and regulatory approvals

- Regulatory approvals from MERA, DoE, MEPA
- Project inception meetings at Dedza DEC, TA, ADC, VDC
- Community sensitization meetings to manage expectations

## Land Rights Approval

- Land identified at centre of village for generation
- Land lease agreement signed with community leaders

## System Sizing and design

- Demand surveys carried out at household and business level to assess load profiles
- Network reticulation surveys - for distribution grid design using GPS coordinates
- System design by UoS, in dialogue with generation supplier

## Customer Sign-Up

- Applications received from potential customers
- Registration criteria: within 600m radius and payment of connection fee (MK 20,000)
- Customers indicate which tariff they want, but able to change at any time

## Procurement and Installation

- Containerised generation, LV AC distribution grid, house wiring and smart meters
- **Mthembanji:** PV system provided by Sustain Power, (South Africa) Distribution by BNG (Lilongwe)
- **Kudembe:** generation and distribution by BNG.

## Business Modelling and Tariff Setting

- Detailed cash flow forecasting
- Balancing operation costs, replacement of components with customer ability and willingness to pay.
- Tariff bundles for domestic, business and institutional customers

## Commissioning

- Coordinated by BNG and UP, with remote support from UoS, Sustain Power and Steamaco
- Testing and troubleshooting

## Operations, maintenance and data analysis

- Site agents collecting tariffs
- Maintenance contract with BNG for regular trips and call outs
- Data collection through smart meters, remote monitoring and surveys willingness to pay.

# 3 Approach to data collection and analysis

***Performance monitoring of microgrids through robust data collection has several benefits for multiple stakeholders in the microgrid sector including system operators, donors, investors and policy makers. A key aim of EASE has been to capture operational data through smart meters, remote monitoring and social impact surveys to inform the microgrid sector.***

steamaco

SUNNY PORTAL powered by ennexOS

KoBotoolbox

## 3.1 Smart metering

*Smart meter antenna on a distribution pole (Mthembanji)*

Smart meters designed exclusively for solar microgrids provide real-time data on a variety of factors, such as revenue generation, demand, frequency of payments, and connection status. Data is typically accessible by an API, spreadsheet downloads, or an online user interface. The microgrids employ SteamaCo [6] smart meters, providing a novel way to track energy consumption, enabling mobile phone payment for electricity and allowing for remote switching and remote data logging. SteamaCo's mobile-enabled bitHarvester keeps connected assets in continual communication with a cloud platform and enables users to manage linked assets in real time through a uniform online interface. Through the cloud platform, real-time data on sales, demand, and smart meter uptime is accessed for analysis (see section 5 onwards).

## 3.2 Remote monitoring

The majority of currently available remote monitoring systems (RMS) track functionality and performance of energy generation systems, and provide technical assistance for system operators by making it easier to conduct maintenance tasks in remote areas. They also enable sustainability evaluation of off-grid renewable energy systems after the project is finished. Similar to smart meters, RMS provide data download through customised web portals. Sunnyportal [7] is an online tool from SMA that allows microgrid system operators and researchers to monitor and configure systems as well as to view system data. Sunnyportal is used to access and monitor generation and storage remote monitoring data, accessible for weekly or daily download and logged at 5-minute intervals. A custom-built temperature logger installed in March 2022 measures interior, external, and battery temperature, logged at 10-minute intervals and transferred to a cloud platform using the site's 3G Wi-Fi network.

## 3.3 Surveys

Through surveys and unstructured interviews, precise qualitative and quantitative data are collected from the community to gain insight on how the electricity is being used and the social impact it has on the community. At Mthembanji, 'Customer journey' surveys were conducted through UP enumerators with all microgrid customers (n=60) through smart phones using the kobocollect app [8], a digital data collection platform recording survey responses on mobile devices and uploaded to a digital server through mobile data or Wi-Fi connection. Following a baseline survey prior to microgrid installation, two follow up surveys have been conducted at 10 and 18 months after installation (see section 7 for analysis).

*Conducting customer journey surveys with smart phones*

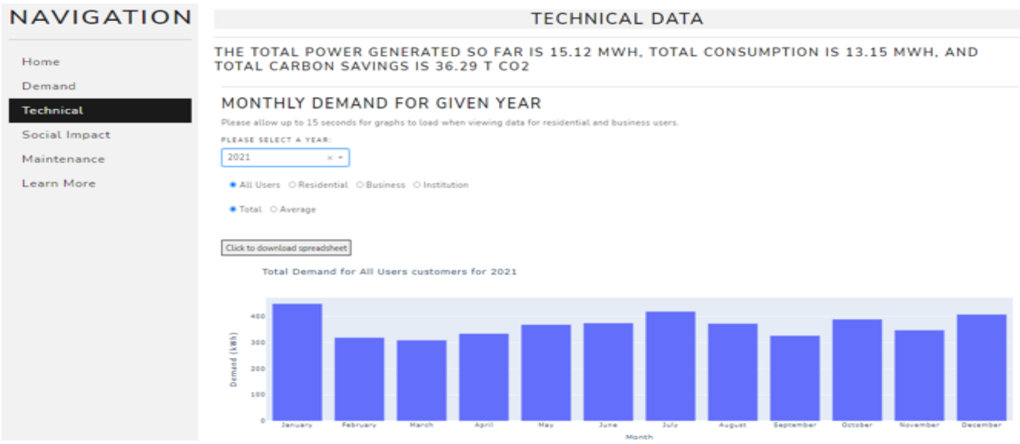
## 3.4 Project management documentation

Project management implementation records, such as meeting minutes, budgeting spreadsheets, invoice repositories, and project diaries, provide access to valuable qualitative and quantitative data. Information obtained using these techniques inform Key Performance Indicators relating to CAPEX and OPEX amongst others, and came from EASE project partners utilising a shared file system storing invoices, technical designs, project Gantt charts, photos and budget spreadsheets used to inform the proceeding analysis.

## 3.5 Data analysis and visualisation

Since installation at Mthembanji, the microgrid has been collecting valuable data on technical, economic and social impact performance through smart meters, remote monitoring and enumerator surveys. With this data, a team of students at Strathclyde University have been programming a data visualisation platform as part of the Solar Microgrids for Sustainable Development VIP4SD project [9]. The platform is intended as a tool that enables easy monitoring and evaluation of data to understand microgrid performance, ultimately informing business strategies for the scaling of microgrid operations in Malawi. Data is collected through third party APIs and analysed through python, currently hosted on the Heroku platform [10] which allows free hosting. A description of the analysis presented on the platform is outlined below. The tool can be accessed here:

[http://ease-microgrid.herokuapp.com/](http://ease-microgrid.herokuapp.com/)




**Technical Indicators** relate to performance of the generation hub mostly taken through the Sunny portal API. These include PV generation, consumption, battery temperature, system downtime, and system efficiency. Carbon savings are calculated following the UNFCCC methodology for mini-grids.

**Demand Indicators** include revenue, monthly demand and hourly load profiles. A detailed spreadsheet containing hourly load profiles for an entire year (8760 data points) is available for download, showing the mean, median and quartile load profiles for single customer segments (residential, business and institutional) as well as the whole microgrid. These load profiles show measured energy use for previously unconnected customers and offer a valuable aid to microgrid design.

**Social Impact indicators**, taken from analysis of enumerator surveys, show customer responses to questions on the impact of the microgrid on their quality of life. Specific topics include household finances, education, health and communication, and the impact on women and girls.

Each indicator has a description of where the data came from and an option to download the data as a spreadsheet. The data analysis presented through the tool is intended to deepen understanding of the current microgrid's performance. Lack of data on microgrid performance, sustainability and social impact is recognised as a barrier to scaling up of microgrids and other decentralised renewable energy infrastructure. It is intended that this platform will help in removing these barriers, through improving technical design and business models as well as informing policy. Findings also contribute to the business and operational planning concerned with future microgrids deployed as part of the EASE project.

# 4 Project development and installation experiences

***As the first project of this type implemented in Malawi, the project faced significant challenges including foreign capital constraints, lack of local capacity, supply chain and regulatory hurdles, contributing to long timelines. Skilled local technicians and field staff with international remote support allowed for rapid deployment once components arrived.***

For both sites, a site selection exercise scored potential villages in Dedza based on strategic indicators such as distance to grid, population density, accessibility and economic activities. Final site selection involved discussion with District Councils and Ministry of Energy to ensure they were not earmarked for grid connection in the near future. Uncertainty on rural electrification plans and likely grid encroachment caused delays and increases risk of future stranded assets. Structured questionnaires targeted to households and businesses in the chosen sites provided input into key system design metrics and included indicators such as current and expected energy use estimation, ability and willingness to pay, existing and aspirational businesses activity and other informative social and demographic indicators. Data collection was carried out using kobocollect via trained enumerators. UoS conducted initial system designs based on customer surveys, with component sizing and techno-economic modelling carried out through HOMERPro [11].

## 4.1 Mthembanji

A procurement process including both Request for Qualification and Request for Proposals was carried out for supply and installation of the microgrid based on initial designs. Due to the nascent nature of the microgrid sector in Malawi huge disparity was found in the quotes for tender, with the highest an order of magnitude larger than the lowest, and various levels of experience and skills offered from local and international suppliers. Sustain Solar (South Africa) was selected to provide the generation hub with BNG Electrical to install it along with the distribution grid. Final component sizing of the generation system followed cost negotiations with the supplier and takes account of future demand growth.


*Malawi Energy Regulatory Agency (MERA) inspecting the Mthembanji generation hub*

Regulatory and administration hurdles included VAT waiver applications to Ministry of Finance, submission of Environmental and Social Management Plan to Malawi Environmental Protection Agency (MEPA), and tariff approvals from Malawi Energy Regularity Agency (MERA). Following further delays due to Covid-19 restrictions and programme related administrative challenges, the installation team completed the distribution grid and customer premises wiring in June 2020. The delivery of the generation system from South Africa added transport and insurance costs, along with additional time delays. PV modules were installed and wiring checks completed before the system went live in July 2020, with customers switching on lights for the first time. A week of testing involved monitoring battery state of charge to assess whether the design assumption of load and system sizing were correct, and dealing with technical issues getting the smart meters online necessitating calibration of mobile network integration. The site was visited by representatives from MERA, who assessed the quality of the installation, granting approval for the sales of electricity.

## 4.2 Kudembe

*Kudembe generation under construction (top) and teamwork to run distribution cables (bottom)*

BNG Electrical (Lilongwe) were selected to supply and install both generation and distribution systems for Kudembe. While impressed with the workmanship and ability demonstrated in Mthembanji, there was also an impetus to build local capacity and extend the value chain closer to Malawi, while reducing transport and insurance costs from transportation from South Africa. However, although some components/materials were available locally, many had to be purchased from South Africa and lack of foreign currency availability in Malawi meant importation delays were still significant. Local capacity for fitting out the shipping container with advanced insulation materials was also lacking, adding further delay.

Bureaucratic hurdles arising from the nature of working with large organisations (UP and UoS), currency devaluations and inflation offered further challenges, causing frequent changes in component prices and necessitating frequent budget revisions. Following regulatory approvals in line with those for Mthembanji, the system was installed in September 2022. Both systems took less than 3 weeks to install both generation and distribution systems once all components were on site.

## 4.3 Summary of success and challenges

The development, installation and commissioning of both microgrids faced serval challenges resulting in significant delays to planned schedules. These have been grouped into themes including: Site prospecting and Stakeholders, Engaging with local and international organisations, Regulatory/Policy, Financial, Supply chain and Administrative hurdles. Table 1 highlights key challenges and lessons learned from field experiences, along with the implications for future microgrid deployment.

*Table 1: Experiences gained through development and installation*

| Theme | Experiences | Lessons Learnt to inform future installations |
|---|---|---|
| Site prospecting and Stakeholders | Site prospecting activities and gaining local permissions from District Council, Traditional Authority Leaders and community require significant fieldwork resources. Challenges setting up an energy committee, local politics | Standardising approaches to local stakeholders and community sensitisation can save time and resources on developments. Budgeting for project development fieldwork necessary. Malawi Integrated Energy Plan expected to help with these processes. |
| Engaging with local and International organisations | Using Sustain Solar, an experienced international supplier provided valuable in technical support specifically with the generation design. Similarly using qualified and experienced local contractor was essential for installation and maintenance arrangements. | Paying for highly qualified local and international contractors is worthwhile in the early stages, eventually the high costs can be mitigated through training in-house staff on maintenance requirements for microgrids. |
| Regulatory/Policy | Initial uncertainty on regulatory requirements and licensing, clarity gained once microgrids framework came out. Producing Environmental and Social Management Plans meant for larger infrastructure projects caused lengthy delays and utilised high amounts of resources. | Lobbying for reduced regulatory requirements, especially for smaller microgrids. Set up an Environmental and Social Management Framework for all mini-grids to reduce having to do an ESMP for each new project. |
| Financial | Currency exchanges caused budgetary issues. Similarly lack of available foreign capital. Inflation caused prices to fluctuate, sometimes daily, making budgeting challenging. | Project budgets should be mindful of FOREX risk and incorporate contingencies. Project managers need to track exchange rates and quantify how changes will affect activities, allowing back-up plans for currency changes. |
| Supply chain | Procurement challenges with companies that haven't installed microgrids before leading to high prices. Lack of local availability of components, necessitating purchasing from South Africa, causing further delays. | Strengthening supply chains, ensuring locally available microgrid components will reduce delays and flexible microgrid design which allows for substitution of components according to local availability |
| Administrative hurdles | Working through bureaucratic processes with large organisations such as NGOs and University caused delays in making payments and auctioning purchase orders | Justification for social enterprise frameworks – more nimble, flexible and efficient |

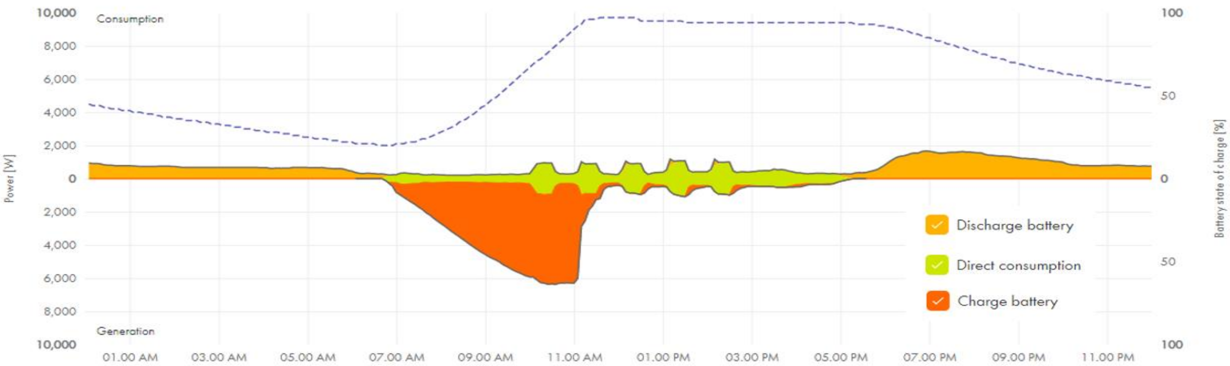
# 5 Technical operations

***Solar PV with Lithium-ion batteries offers low maintenance generation and storage, with effective remote monitoring assisting in troubleshooting. The microgrid has generally performed efficiently, providing reliable energy to communities, demonstrating resilient energy delivery in areas vulnerable to climate shocks. Challenges were experienced with the smart meters from technical faults and mobile signal causing blackouts necessitating call out fees for maintenance engineers.***

## 5.1 Generation system

PV modules with SMA inverters have generally provided reliable power with low maintenance requirements other than regular cleaning of the panels. The remote monitoring through SMA Sunnyportal offers direct insight into generation, consumption and battery state of charge, and allows rapid identification of faults and remote troubleshooting. The system was found to have excess generation but no excess storage capacity. Batteries generally discharge close to full capacity overnight then reach full charge by mid-morning, as shown in  which shows a typical daily energy flow for the batteries. The utilisation rate for the plant is low at 21.6%, indicating spare daytime energy currently wasted offering an opportunity for increased demand and revenues. The annual generation for 2021 was 7,293.9 kWh, with a seasonal trend revealing lowest generation during the rainy season in February.

*Figure 2 Typical daily energy flow for batteries*




*Inverters and controls within the shipping container (Mthembanji)*

The shipping container houses the inverters, controls and ancillary components, with an insulated, air conditioned room housing the lithium ion batteries at a controlled temperature. The containerised solution offers security from theft, easy access and additional space to store tools, equipment or products, while being easy to transport and locally available in Malawi. The downside of the use of shipping container included increased cost of CAPEX, and increased temperatures discussed below.

Site agents use the container as a base where customers can find them to top up their accounts through SteamaCo. Site agents were trained in conducting a power loop to reset the system if required, and alerting faults to management staff; which have been few.

Both systems employed Lithium-ion batteries, the move away from incumbent lead acid batteries follows an industry trend: Lithium-ion batteries are decreasing in cost, offer significantly longer lifetimes than lead acid, can be discharged to much lower depth of discharge and require less maintenance than lead acid. Tesvolt batteries used in Mthembanji offer a 10 year warrantee, BYD at Kudembe 6 years. The main drawback to Lithium-ion storage is the low recyclability level, currently only offered by returning end of life batteries to Germany at increased cost for the project developer, although the situation may have improved by the time the batteries reach their end of life.

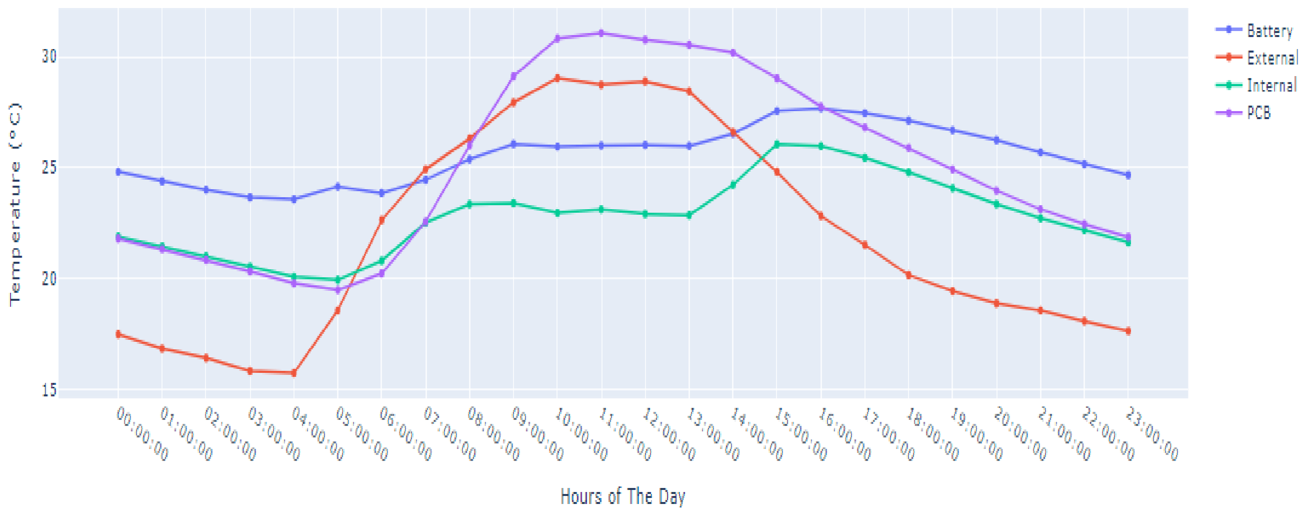
The Tesvolt batteries link to the Sunnyportal RMS, with additional data available through their bespoke battery management system accessed through a laptop connection on site. Depth of discharge levels are pre-programmed, with the batteries cutting out at 20% and automatically powering up when this is reached. Experiences of Tesvolt of Mthembanji have been positive, with few technical issues experienced.

*Installing the battery temperature monitor at Mthembanji*

*Tesvolt battery display at Mthembanji*


Battery performance and lifetime is directly linked to operating temperature, which is a challenge when housing them in shipping containers in the hot climates. Despite being installed in an air conditioned room, during periods of high temperatures in the October dry seasons the system shut down due to high temperatures. Logging the temperatures through a bespoke battery monitor has helped to detect high temperatures and adjust the air conditioning accordingly. Investing in battery temperature logging equipment can prolong battery lifetimes, designing cooling systems adequate for current and future temperatures (expected to rise due to climate change) essential for technical design.

*Temperature data for a typical day, logged outside and inside the shipping container, on the batteries and within the logger*



## 5.2 Distribution grid and house wiring

Customer premises wiring in conduit

Electricity is distributed radially at 240V single phase through 50mm$^2$ aluminum cable on 9m wooden poles. The decision for low voltage single phase reduced capital costs but has limited the customer base to a 600m radius from the generation hub and prevented the use of 3 phase motors for agricultural use. However, holes are already drilled in the poles and the grid can be upgraded to 3 phase if and when demand grows. The design and installation of the distribution grid to Malawi Grid Code ensures that should the national grid arrive; it can utilise existing assets. The distribution grid efficiency, measured though comparison of demand measured by smart meters across the village and dividing it by the total consumption of the grid measured at the output of the inverters, varies seasonally between 68% to 90%. Wayleaves were acquired from customers prior to installing the distribution lines, which can result in conflicts on land use. Challenges were experienced with customers trimming trees with branches falling on power distribution lines necessitating contractor call outs at cost, highlighting the need for enhanced community engagement. Vandalism of the distribution grid was also experienced, discussed more in section 7.

House wiring was offered to customers as part of the connection fee (MK 20,000), comprising 4 internal bulbs and 1 external bulb, an AC plug socket and consumer distribution board, with wires enclosed in plastic conduit to MERA standards. Some issues were found with customers not using appliances correctly, or practicing unsafe wiring when plugs break. This again highlights the need for effective customer engagement, particularly on electrical safety.

## 5.3 Demand

Total monthly demand for 2021 (Figure 3), disaggregated by customer segment reveals domestic customers have highest demand, ranging from 350 kWh to 325 kWh per month, with a seasonal trend that reduces in February's rainy season. The total business demand is lower, ranging from 103 kWh to 65 kWh, and is generally more steady. This contrasts to Figure 4 showing average monthly demand per customer for each customer segment, indicating business users have highest demand per customer (9-15 kWh per month). For both charts the institutional demand is low, for Mthembanji a school and a church.

The data analysis helps to understand the breakdown of demand by customer segment and clearly shows the value in promoting daytime productive use of energy customers. It also allows insight to design seasonal tariffs designed to benefit customer segments accordingly.

*Figure 3: Total monthly demand for 2021 per customer segment*

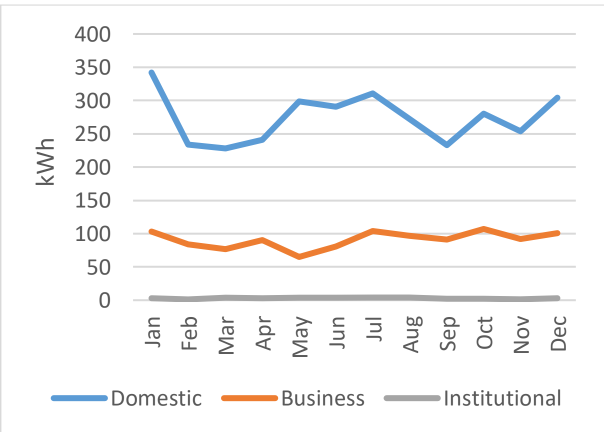
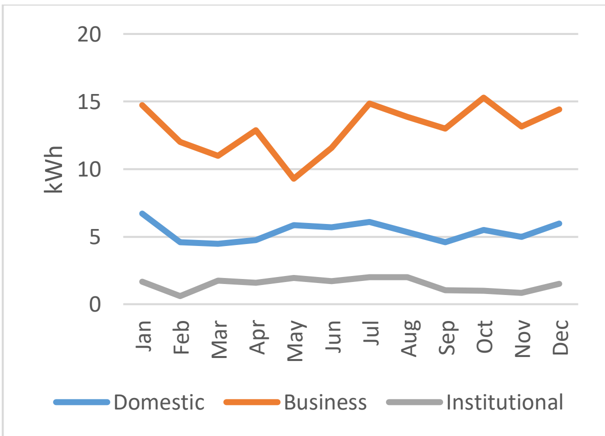



*Figure 4 Average monthly demand per customer segment for 2021*



Load profiles gathered from Steamaco data for total microgrid demand disaggregated into customer segments is shown in Figure 5, taken from analysis of hourly data (8760 data points) through 2021, including mean, median, 25th and 75th percentiles. The high proportion of residential customers is reflected in an evening peak with a second, less prominent daytime peak at 11am. The evening use tails off to a low at 4am, indicating customers keep their lights switched on until sunrise. Figure 6 shows customer segment load profiles, highlighting the higher demand and both daytime and evening peaks of business customers, and low demand of institutional customers.

*Figure 5: Average load profile for entire microgrid*

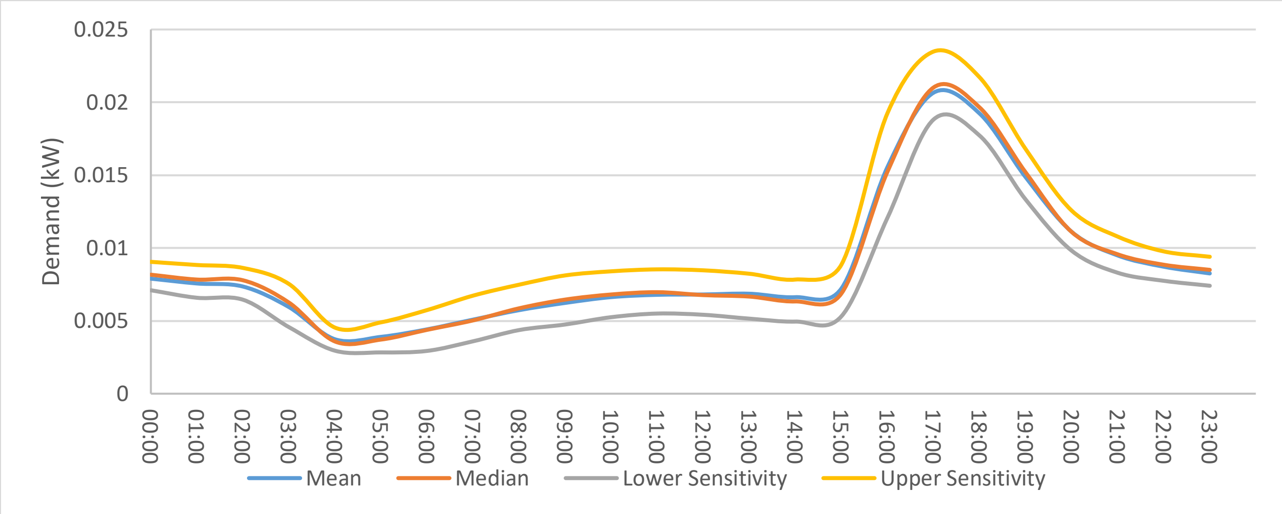
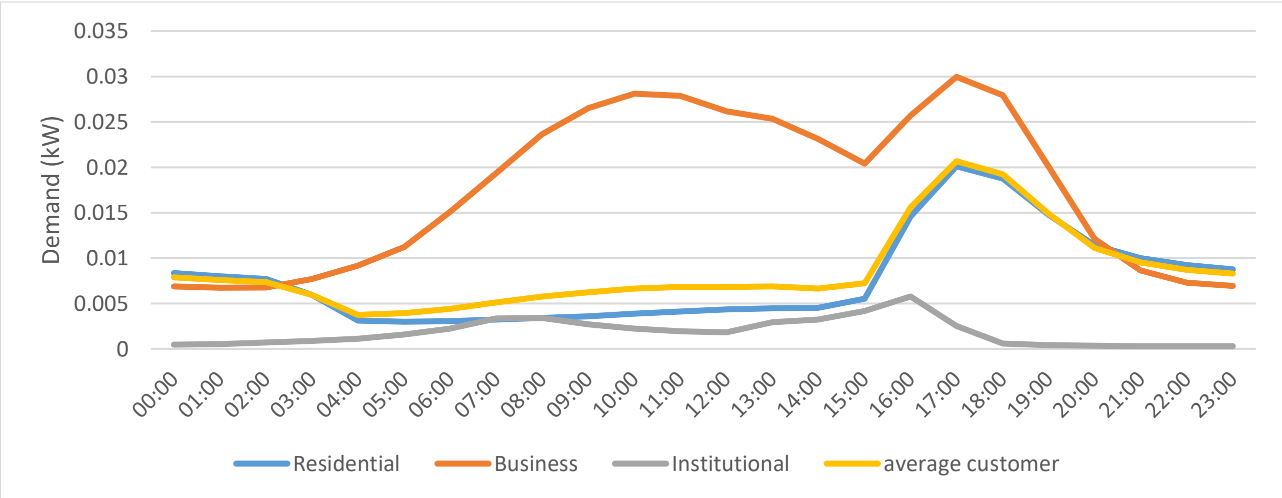



*Figure 6 Customer segment mean load profiles*



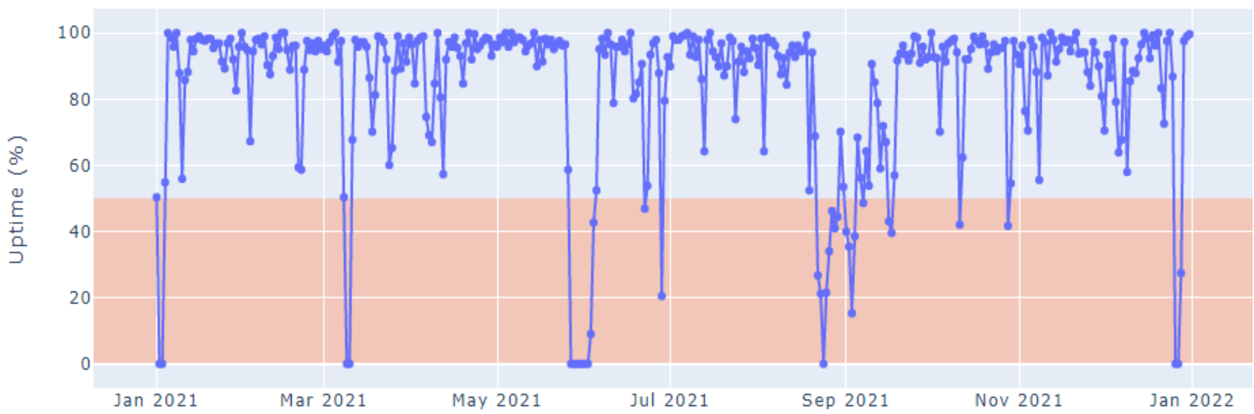

## 5.4 Smart meters

SteamaCo smart meters offer innovation in remote switching, digital payment platforms, and real time data on demand, revenue and system downtime. It also allows for dynamic tariff changes, insight on customer segment demand, and real time insight on revenue. Additional functionality includes enabling payments through mobile money, although this is yet to be implemented due to the low uptake of mobile money in the village. Power limits can also be set for customers to prevent overuse of energy. The online user interface allows access from anywhere in the world, updating tariffs, remote switching and the functionality to send customer SMS text to inform them of new tariff deals or warn them of scheduled maintenance outages. The core communicates with pole mounted edge meters (one per connection) through SMS, with connection to the cloud through a local 3G wifi network. Additional to the meter and core capital costs are annual SaaS costs, based on the data used.

Despite offering significant innovation in control, demand management and flexible payments, the new technology came at a cost. Being the first time implementing them in Malawi, significant technical issues were experienced causing frequent blackouts, impacting negatively on customer satisfaction and microgrid income.

Caused by a combination of poor mobile signal and technical constraints with the smart meters, the issues are a symptom of trialling new technology in remote areas in a new environment. Resetting smart meter cores requires climbing equipment and specialist knowledge through a call out from maintenance contractors in Lilongwe, resulting in expensive maintenance costs. These have since been mitigated through training local field managers, avoiding contractor transport and call out costs. Additionally, as mobile signal improves and smart meter reliability improves with further product releases these issues should reduce, but in the short-term tracking and monitoring technical issues such as these, and focusing on ways to reduce them must form a key element of microgrid developers operational plans.

*Daily communication uptime at Mthembanji throughout 2021 – the red zone indicates when customers had a majority of the day without access. Faults were mainly due to smart meter connectivity*




## 5.5 Carbon savings and climate resilience

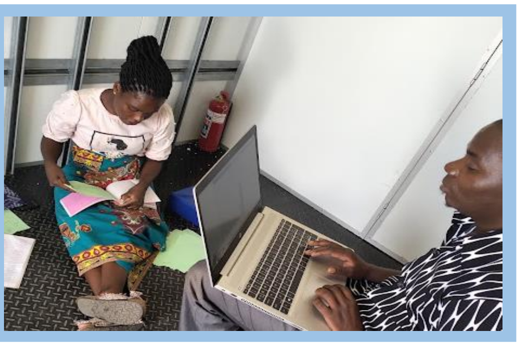
Total potential carbon savings recorded for the microgrid at the time of writing are 37 tonnes, or approximately 1 tonne per month. The calculation assumes that the energy generated by the Mthembanji microgrid would have been provided by an electricity generation system using a diesel generator, and this carbon has in effect been displaced. Potential carbon savings are calculated by taking the total amount of energy generated by the microgrid each year and multiplying this by an emission factor dictated by our system size and load factor level. This follows an established carbon displacement methodology for minigrids published by the UNFCCC [12]. Solar PV offers one of the lowest carbon generation sources and is expected to play a necessary role in a low carbon future for Malawi.

On 24th January 2022, Cyclone Ana hit Malawi, causing widespread destruction and loss of life in southern regions. Significant infrastructure damage was inflicted on hydro generation plants feeding the national grid, increasing the frequency and severity of blackouts across the county on an already constrained grid. At the time of writing (October 2022), 10 hour blackouts across the vast majority of the country are still the norm. In contrast, the microgrid at Mthembanji demonstrated resilience by staying functional and providing reliable power during the cyclone period and the months since. Decentralised renewable energy infrastructure such as microgrids can offer increased resilience and security of supply over centralised generation, attributes expected to become increasingly desirable as Malawi faces more extreme weather events as a result of climate change.

*Damage to Kapichira hydro generation in 2021, Mthembanji remained functioning while most of the country experienced blackouts*

# 6 Business model and financials

***Capital and operational costs have been found to be high compared to benchmarks, reflecting the nascent market of microgrids in Malawi. Revenue from electricity sales just covers site based operational costs of maintenance contract, data and site agents, but doesn't cover wider organisational costs such as transport and staff salaries.***



## 6.1 Capital costs

Itemised CAPEX costs for both Mthembanji and Kudembe are summarised in Figure 7. The cost per kW of USD 8,869 for Mthembanji and USD 9,924 for Kudembe is towards the higher end of current benchmark figures, with the African Minigrid Developers Association stating that microgrid CAPEX costs in Sub-Saharan Africa currently range from 4,000 USD/kW to 11,000 USD/kW [13]. Not included in these costs are development costs including staff time for site prospecting, community engagement, fieldwork, technical design and project management, as these were covered through EASE funding which would increase the CAPEX costs further.

*Figure 7 CAPEX costs (USD) for both microgrids*

| CAPEX Item | Mthembanji | Kudembe |
|---|---|---|
| **Generation** | $ 55,603 | $ 41,847 |
| **Distribution and smart meters** | $ 27,968 | $ 39,443 |
| **Installation and fees** | $ 18,425 | $ 27,084 |
| **Total** | $ 101,995 | $ 108,373 |
| **Cost per connection** | $ 1,700 | $ 2,167 |
| **Cost per kW** | $ 8,869 | $ 9,924 |

The high costs are largely attributed to this being the first project of its kind in Malawi, and costs are expected to reduce as more microgrids are installed and economies of scale are achieved along with efficiencies in procurement and supply chains, and reducing costs of the technologies.

Transport costs from South Africa were high for both projects, and as local supply chains for solar equipment are strengthened these are expected to come down. The choice of BYD batteries for Kudembe offered significant savings over the more expensive Tesvolt, however monitoring the performance and lifetime of the two types of batteries will determine if the initial low cost results in higher costs in the long run. The cost of PV has fallen exponentially over the last decade and is expected to continue to fall, further improving solar microgrid capex. Similarly lithium ion battery prices are expected to fall as production increases [14].

The higher distribution and installation costs for Kudembe were largely due to inflation and foreign exchange rate fluctuations, pushing local fuel and labour prices up resulting in significant cost increases for local component and contractor costs. This reflects the impact of macro-economic volatility on local supply chains and microgrid project costs, and is likely to be a key influencing factor on future microgrid CAPEX in Malawi.

*Construction of Kudembe generation hub*

## 6.2 Operational costs

Site based operational costs for Mthembanji total USD 316.4 per month on average or USD 3,796.80 annually. They include site agent and security guard salaries, data and SaaS fees for Steamaco, and a generation and distribution maintenance contract , but do not include field and management staff costs, transport costs and business overheads, as these have been covered through EASE grant funding. The cost per customer per month of USD 5.27 is already on the high side of bench mark estimates for sub-Saharan Africa of USD 2.50 – 6.00 [13]. A comparison with monthly revenue reveals income only just covering site based costs, compromising financial sustainability without interventions on tariffs or demand.

The total demand or energy sold for 2021 is 6,369.29 kWh, which makes the cost of power excluding CAPEX and subsidies for the period in question 0.6 USD/kWh. These KPIs are of particular interest to investors and donors, and more generally for tracking ongoing financial sustainability. Microgrid developers should be continually looking for ways to increase the amount of kWh's sold and decrease the costs required to produce that electricity in order to provide affordable tariffs while maintaining sufficient income to ensure financial sustainability.

For the majority of mini-grid developers in Africa, OPEX and revenue are almost the same, due to high operational expenditure from challenges of reaching remote locations and the need to trial unproven operational strategies, coupled with the fact that revenue is low - reflective of rural energy consumption across the board (including solar home systems, or grid connections) [13].

This is common when operating decentralised energy assets in Malawi, with a close balance of OPEX costs against revenue and limited margin to cover wider business costs. To achieve financial sustainability, strategies must be undertaken to reduce costs through operational efficiencies, and to increase demand through promoting PUE, increasing the number of connections, and installing more microgrids.

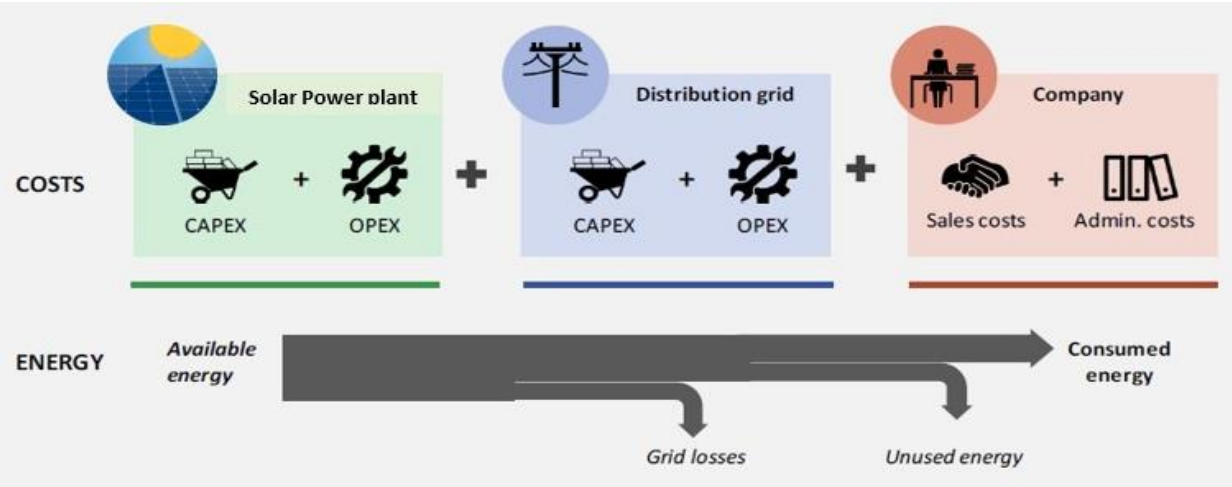
*Maintenance activities on the distribution grid*

For Mthembanji, the majority of OPEX costs come from a maintenance contract with a Lilongwe based electrical contractor, currently the only option given the lack of technical capacity to conduct robust maintenance on microgrids. These costs can be reduced when operating at scale through in-house maintenance technicians, with salaries paid through central funds, and only paying for transport/material costs needed for maintenance trips. Travel to different microgrid sites could be combined and efficient logistics strategies employed to reduce travel times and save on costs.

Another way to address financial sustainability is to increase revenue through higher demand, either through increasing the number of customers or promoting daytime electricity use. At Mthembanji this is being addressed through the implementation of rice milling operations at the site, and expanding the generation and distribution to cater for more customers.

## 6.3 Tariffs

Tariffs balance costs of producing energy with the communities' ability and willingness to pay for electricity. Through smart meters, innovative and dynamic tariffs have been tested and adjusted, following extensive community engagement and feedback. The tariffs summarised below were designed to include operation costs, staffing costs and replacement of components at end of life.




Tariffs are paid through site agents in a PAYGO format, where customer balances are topped up through the SteamaCo platform. Mobile money payments are in the process of being trialled to reduce overheads and increase efficiency and ease of use for customers, with planned full roll out by 2023.

According to MERA's Minigrid Framework[1], for minigrids under 50kW the tariff is an agreement with the community and doesn't need to be approved. The tariffs have been set and adjusted through ongoing community engagement and negotiations on willingness to pay, with different tariffs designed to cater for different customer segments, as outlined in the table below.

*Figure 8 Tariff summary for Mthembanji and Kudembe*

| Bundle | Services | Payment type |
|---|---|---|
| Banja Monthly ***(Household)*** | A set allocation of energy (260 Wh per day) which approximately equates to a daily service of:<br>- 3 lights for 3 hours<br>- 1 light for 8 hours<br>- 1 hour of TV<br>- 2 hours of phone charging | Monthly service fee |
| Ufulu (Freedom) | Unlimited electricity paid for per unit. A cheaper rate applies for higher use. | Pay as you Go |
| Ufulu Daytime | Daytime discount 75% reduction in standard Ufulu costs | Pay as you Go |
| Midzi (Community) | Electricity for Schools, Churches or other community groups based on your needs | Pay as you Go |

The Banja tariffs offers a set allocation of energy for a daily fee, which allows for adequate domestic use including lights, phone charging and TV. The Ufulu tariff for business customers is tiered and reduces for higher energy users. A significant daytime discount (75%) promotes demand when excess electricity is available during sunlight hours.

[1] https://mera.mw/downloads/legal-and-regulatory-framework-for-mini-grids/

Tariffs are able to be changed dynamically through the SteamaCo platform and continue to be adjusted based on customer feedback and ongoing business modelling. Customer feedback is gained through site agents and enumerator surveys. Steamaco also allows for appliance financing to be trialed through tariff payment, an innovation which will be trialed in the future.

## 6.4 Revenue and ability to pay

Microgrid financial sustainability, direction of tariff modifications, and business model planning for future microgrids all depend on understanding revenue generation, aiming for a positive balance to be struck between income from electricity sales and operational costs for staff, maintenance and other running costs. Total revenue for 2021 was USD 3,128, following a seasonal pattern peaking at 516 USD/month in July reducing to 180 USD/month in March, with the majority of revenue coming from residential customers (Figure 9).

*Figure 9 Customer disaggregated revenue (USD)*

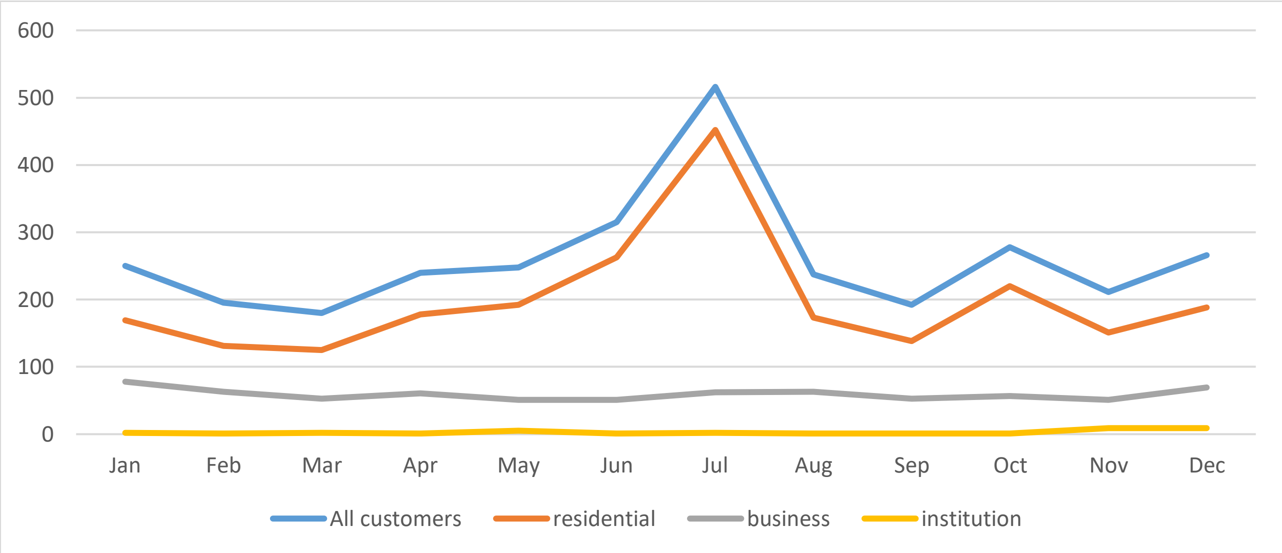
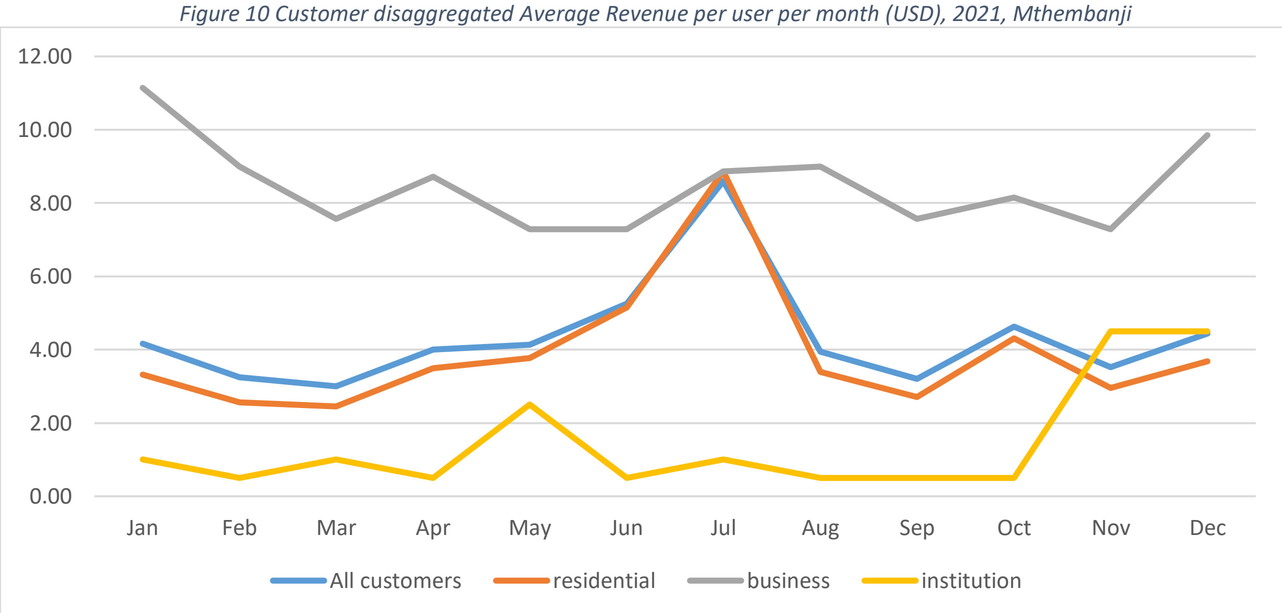



Figure 10 shows Average Revenue Per User (ARPU) per month for 2021, disaggregated by customer segment. Residential ARPU follows a seasonal trend with higher spending corresponding to the rice harvest season in July, while business ARPU is considerably higher and following a less prominent seasonal trend. The mean ARPU for the year is 5.43 USD/month, which is higher than estimates for Tanzania ($4.58), Kenya ($2.96) and Nigeria ($4.83) [13].

*Figure 10 Customer disaggregated Average Revenue per user per month (USD), 2021, Mthembanji*



The seasonal trends corresponding to harvest seasons can be used to plan timings of appliance financing programmes or seasonal tariffs. Acknowledging the mean ARPU of businesses (USD 8.48) is more than double residential (USD 3.89) highlights the importance of increasing revenue through promoting PUE with targeted business support. Comparison of ARPU with monthly OPEX costs determines financial sustainability with shortfalls or surpluses quantified to inform business planning. In the case of Mthembanji, the income only just covers the monthly OPEX costs, and provides no support for additional staff costs, transport, or wider business costs.

The ARPU data provides valuable insight of rural customers ability and willingness to pay. The tariff was initially found to be too high by the community, resulting in complaints and negotiations conducted over time to find an acceptable tariffs. Ongoing assessment of willingness to pay is essential for finding tariff sweet spots and ensuring customer satisfaction and sustainable levels of electricity consumption that doesn't further impoverish communities. Data sharing of ARPU between microgrid developers progresses the knowledgebase to informing sustainable business models with affordable tariffs.

## 6.5 Productive Uses of Energy


Rural electrification can support small business development while small business development can support the viability of clean energy microgrids, collectively contributing to transformation of the rural economy. The utilisation at Mthembanji has been found to be low, leading to high levels of unused energy during the day. Utilising the unused electricity through promoting of productive uses of energy increases the financial viability of the microgrid while promoting local economic activity resulting in increased social-economic impacts.

PUE can be found in: agriculture (e.g. irrigation, grain milling, electric fencing), manufacturing (e.g. carpentry, tailoring, welding, and looming), and the service sector (e.g. bars and restaurants using electric lights, sound systems, refrigerators, charging stations for mobile phones). Common use applications include electricity used for potable water, public lighting, education, health (e.g. refrigeration of vaccines and anti-venom).

The number of businesses has steadily increased since the microgrid was installed, with grocery shops, barber shops, phone charging and video shows as common businesses with low capital overheads to set up. A capacity building session was run covering business development and marketing for small sales and services, although this increased the number of businesses on the site, it was found that a key limiting factor is availability of business capital to purchase appliances. In order to promote PUE successfully, micro finance companies should be engaged to provide low interest loans to entrepreneurs, both spurring economic development and increasing microgrid demand.

## 6.6 Community engagement

The experiences at Mthembanji have highlighted the need for continued and well planned community engagement, from before the microgrid is installed, to regular engagement throughout the project cycle. Providing electricity to communities that have not had it before requires detailed training on safe use to avoid injury, and ongoing negotiations with tariff have been essential to inform willingness to pay.

A key element of EASE has been training and capacity building, and enabling a two-way dialogue between community and microgrid operator to ensure expectations are managed, complaints and feedback are heard and used to improve the customer service. This has been facilitated through customer contracts, site agents, regular visits from field agents, and specific targeted community trainings.

In 2022 vandalism was experienced in Mthembanji, where members of the community had cut some of the distribution wires. The cause of the vandalism was unable to be determined, however it was followed by enhanced sensitivity raising on the impact of cable theft and its effect on the sustainability of the microgrid, as well as community policing to keep an eye on the infrastructure. Since the interventions there have not been any additional cases of vandalism, highlighting the value of community engagement.

The tariff setting has been the result of ongoing community engagement. Initial cost reflective tariffs were deemed to be unaffordable and reflected through customer dialogue. The current levels are deemed to be affordable, indicated through ongoing payments from all customer segments and fewer complaints, however this comes after regular feedback provided to field managers on cost of electricity and the ability to run a business from them.

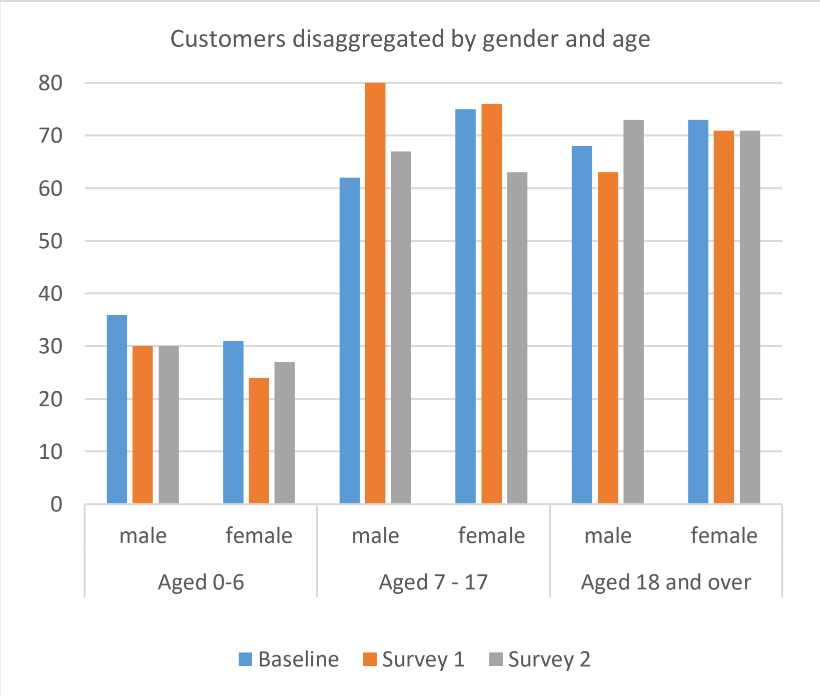
An attempt was made to set up a local Village Energy Committee to deal with community engagement around the microgrid which unfortunately faced challenges due to local politics. Field experiences suggest a strong and well respected Group Village Head is needed to ensure community engagement with microgrid activities and mitigate the issues highlighted above. The project experiences suggest that relying too much on a community management model can lead to complexities and vulnerabilities for the microgrid operation, while having a paid site agent and management staff responsibly for a fleet of microgrids is likely a more reliable and effective approach, although more expensive. Experiences from further microgrids will reveal greater insight into this topic and is an important subject for ongoing research.

# 7 Understanding social impact

***Social impact data collected through surveys shows that energy access directly correlates with participants' expectations for happiness, opportunities, and economic development. Households are much more satisfied with their home lighting and can entertain, work and study in their homes at night. Energy supply infrastructure, availability, convenience, and environmental and health impact from microgrid energy has improved. Participants in the survey are generally satisfied with the quality of the service and the project; they consider it a good development, transforming life in the community and bringing an urban feel to it. However, some customers find tariffs expensive and unreliable, and did not always allow community members to pursue their business venture ideas. The analysis below is for Mthembanji, with surveys conducted 10 and 18 months after installation***.


## 7.1 Demographics

At Mthembanji there are 60 registered customers, serving 335 people, with an average household size of around 6, a maximum household size of 12 and 4 female headed houses. There is a large youth population with ages 7 – 17 being the highest for each survey.



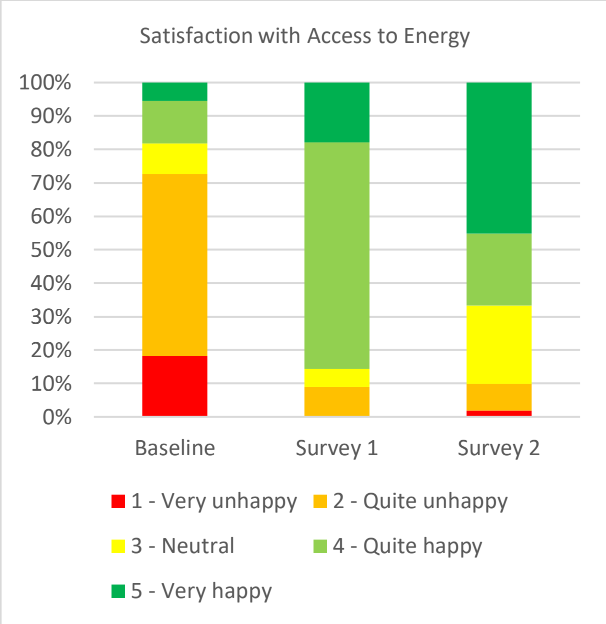

The majority of customers have completed primary school, with 24% completing secondary school, 8% pursuing higher education, and 11% having no formal education. Understanding education levels aids in gauging technical positioning of community engagement, and tracking over long time periods aids in understanding microgrid impact on education. Baseline surveys indicate the majority of customers are farmers (90%), with some running grocery stores or brewing, and some teachers. Follow-up surveys ask if anyone in the household's occupation has changed, and on both surveys this is answered negatively, with the exception of one who indicated they were also running a side business.

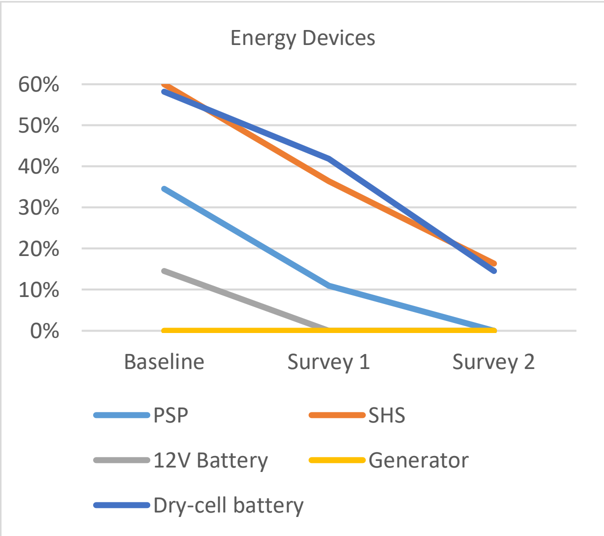
## 7.2 Energy access

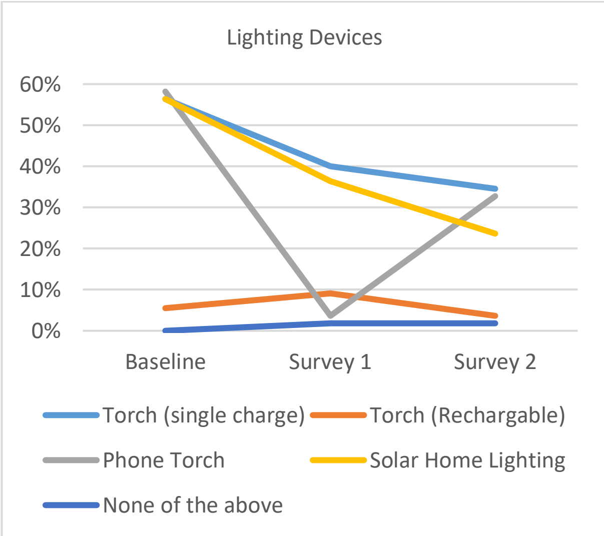
The microgrid provides a connection for 32% of the local population. Since installation, all microgrid customers have reported a reduction in use of non-microgrid devices including PSP, SHS, 12V Battery, and dry-cell batteries. This impacts many aspects of community life, including reducing environmental impact and pollution. Dry-cell battery reductions in particular will benefit the environment as batteries are rarely recycled and leak acid into the soil.

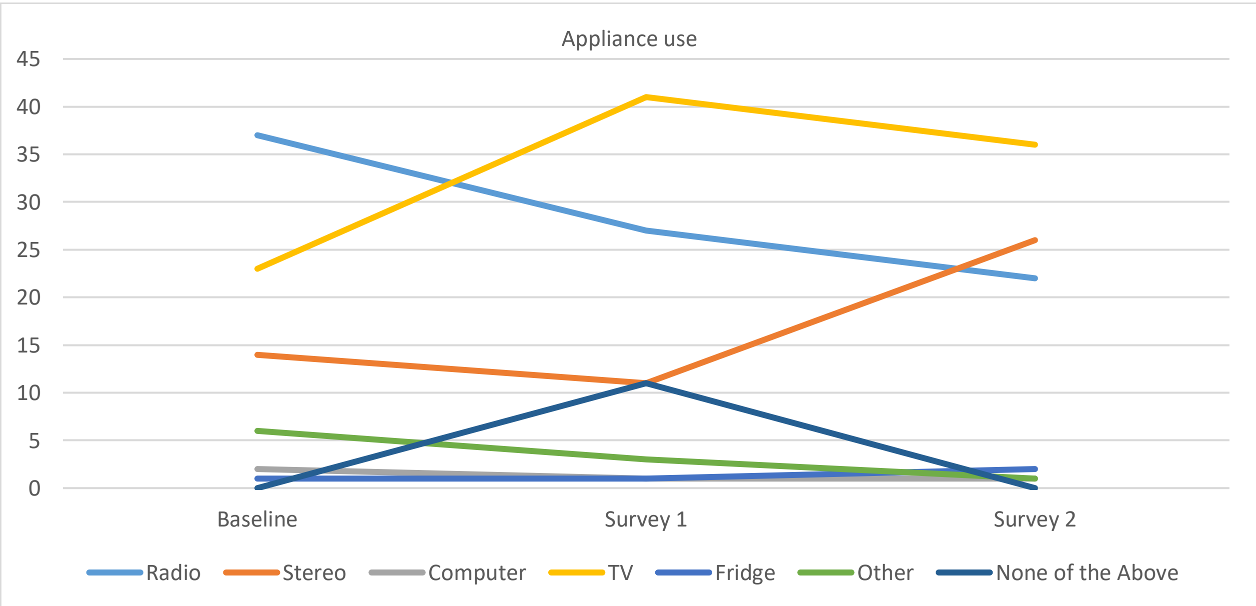
As microgrid lighting became the primary lighting source for 100% of domestic customers, the use of solar home lighting and single charge torches decreased as expected. Phone torch use first reduced then increased, although the majority of phone torch use is outside for kitchens and toilets. Follow-up surveys would determine whether the microgrid lighting is adequate or if additional lighting devices are required. Customers are currently offered four internal bulbs and one external bulb. Surveys have revealed an increase in the use of stereos and televisions, and a decrease in the use of radios. Other trends are unclear given the small sample size. This data will inform community engagement and future appliance financing schemes on the site.

Satisfaction with energy access has increased, with an increase over time of "very happy" and decrease of "very unhappy" responses. Contrary results should highlight issues with the service and be investigated for rectification.

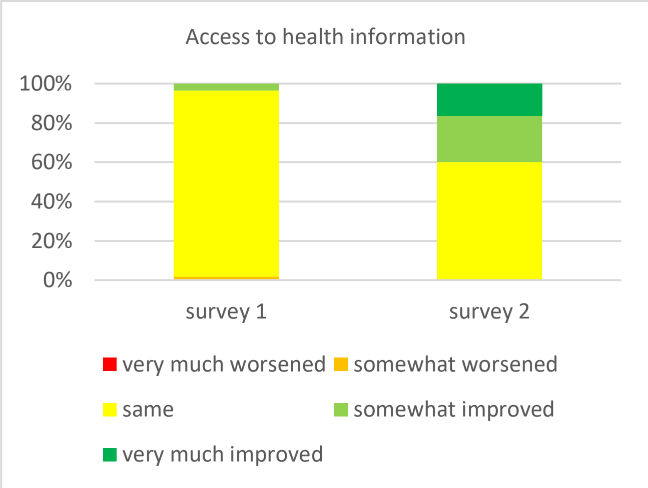


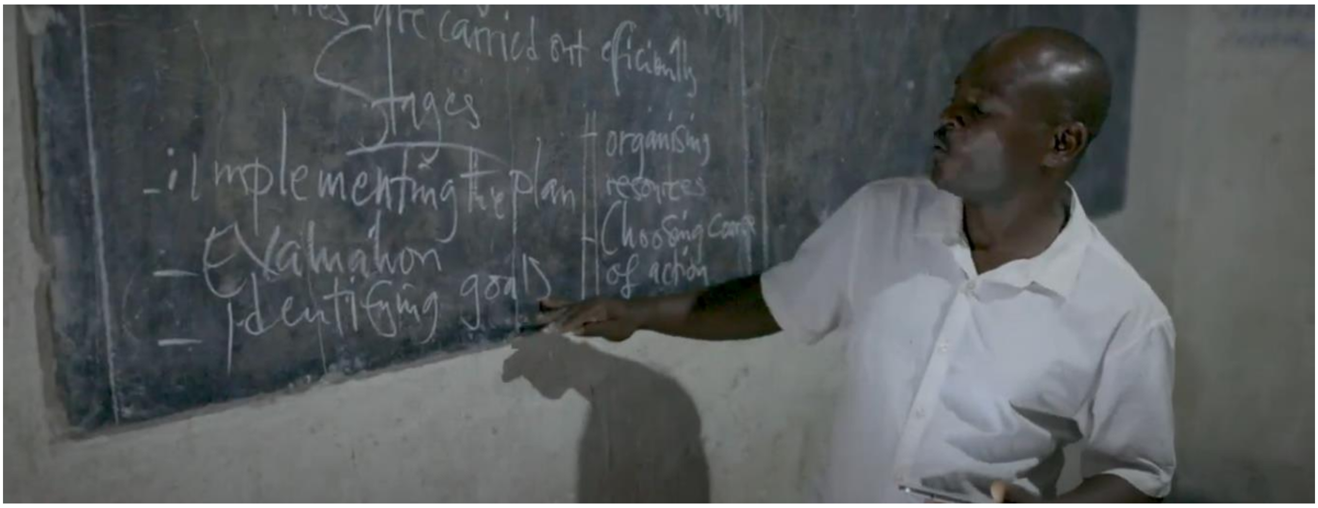
## 7.3 Health, education and communication




Improved energy access can contribute to improved human health in a number of ways. It can ameliorate the conditions in hospitals and health centres through provision of lighting, ventilation, cool storage for vaccines and blood banking. Improved energy access can allow new ways for accessing health information (TV, radio, mobile phone, internet) and it can allow for clean cooking solutions that reduce the use of traditional fuels and exposure to harmful indoor pollution. While the microgrid technology, in general, can create direct health impacts, this cannot be achieved in this community due to the wider lack of health facilities.

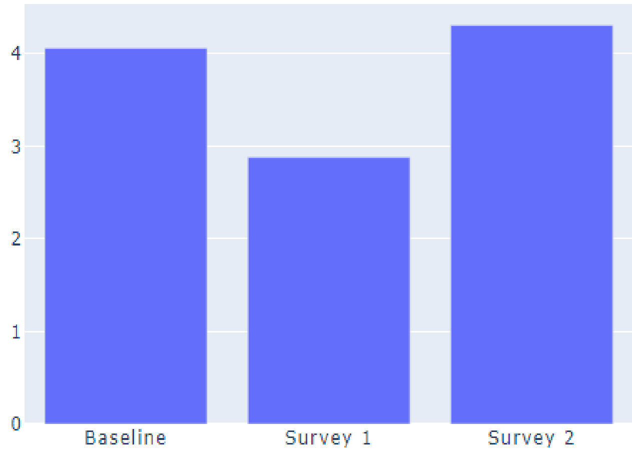
The number of health centres or hospitals has remained at zero, although a newly establish health clinic will be connected when the system is expanded. Due to its small generation capacity, the microgrid was not intended to supply cooking needs and accordingly a reduction in burns injuries has not yet been recorded. Substituting dim or open flame lighting sources with lighting from the microgrid has potential to reduce injuries and improved lighting is expected to reduce eye problems, although further research is needed to investigate this. 40% of customers indicated access to health information has ‘very much improved’ or somewhat improved, when asked how it has changed, responses included “My phone is always charged and I have easy access to information”, and “We have unlimited access to radio because of electricity”, indicating a positive attribution between microgrid electricity and access to health information.

*Evening teaching at Ntandamula primary school, Mthembanji*



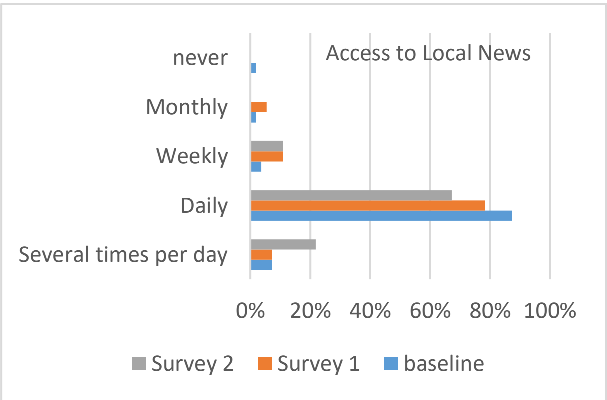
Given the short time in which the microgrid has been operational in Mthembanji and other factors influencing the educational sector, it is difficult to estimate the intervention’s impact on educational outcomes. The research shows that the material setting has changed, and now there are opportunities for learning practices to evolve. Electrifying schools and homes can change learning and study practices, enhancing the education children receive and their results in the long run. The focus groups show the community’s perception that the microgrid has already contributed to improved school grades of their children.

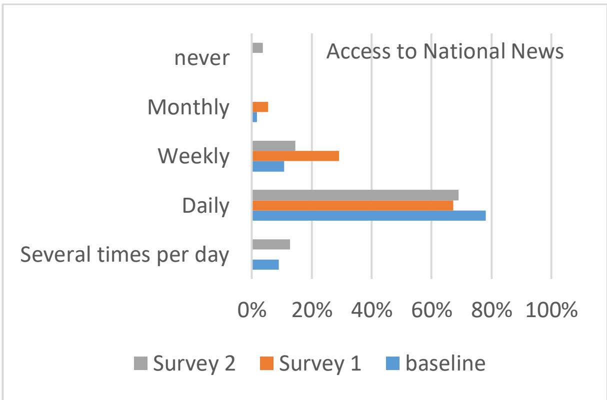
Only one school is connected to the microgrid and accessing ICT through partnership with the Turing Trust. The percentage of households reporting that children study at home has reduced from 92% in the baseline to 89% in survey one and 79% in survey two. The surveys suggests that children are spending more additional time studying in the home since installation, with a reduction from 4.06 to 3.88 hours between baseline and survey one, followed by an increase to 4.31 in survey 2. These figures may be impacted by children spending time studying at school after dark, and further surveys or interviews with customers would be required to make a clear contribution to this from the microgrid.



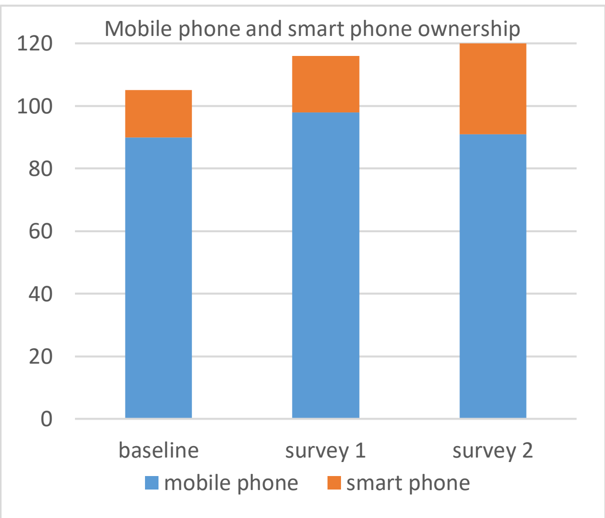

*Average number of hours spend studying in the home*

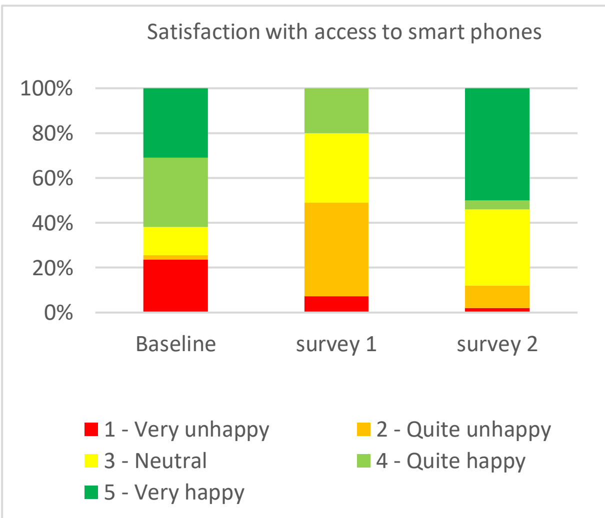
The community's daily news access has reduced between baseline to survey 2, while several times per day access to news has increased over time. Analysis of the KPIs over longer time frames will contribute to an understanding of how access to energy impacts communication and connection to the wider world.



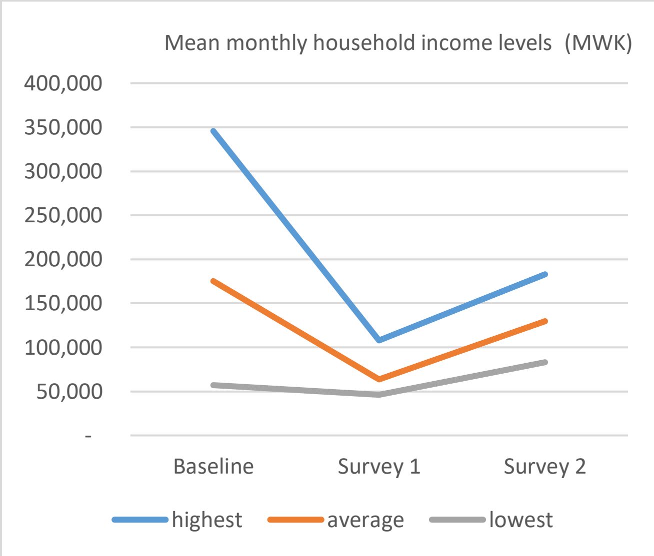




There has been an increase in total phone ownership, with an increasing proportion of smart phones. Customer satisfaction with smart phones since installation is shown in , which demonstrates a general trend of increased satisfaction over time. The microgrid offers in house phone charging for all customers and tracking phone ownership and associated satisfaction is an indicator of how the microgrid contributes to social impact in terms of increased connectivity.



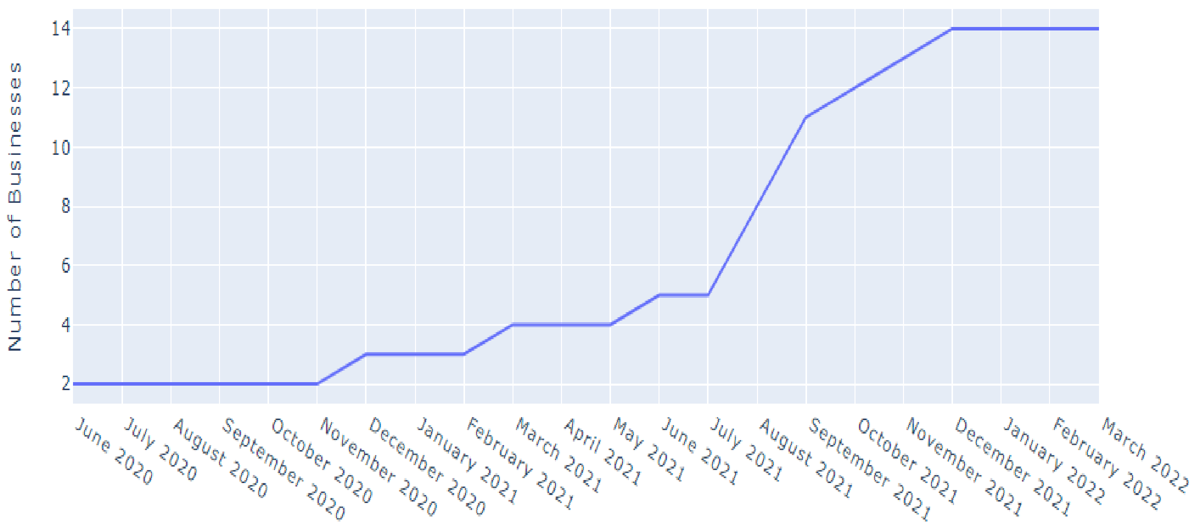
## 7.4 Employment, finance and PUE

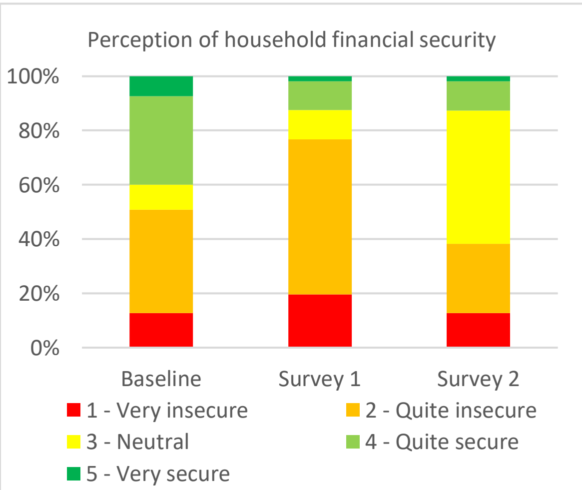



Mean monthly household income data suggest a decrease in income between baseline and survey 1, followed by an increase in both between survey 1 and survey 2. Asking income figures directly through surveys is inherently difficult [15] as finances follow seasonal trends, records generally aren't kept, and few are on set contracts with steady monthly incomes. This is reflected by 24 customers in Survey 1 and 32 for survey 2 stating 'don't know' for all responses.

The number of businesses connected to the microgrid since installation has increased from 2 at the baseline survey to 14 in March 2022. Types of new businesses reported include: video show, grocery and liquor shops with fridges, computer cafés, cold soft drinks, saloons and barbershops. Tracking new businesses is essential for predicting load profiles and modelling microgrid future revenue. All businesses have reported an increase in both income and expenditure since connection to the microgrid.

*Figure 11 Number of businesses and industries connected*




Perception of financial security corresponds to satisfaction with tariff. The percent of customers feeling very insecure or quite insecure increased from 51% in the baseline to 77% survey 1, then reduced to 38% in survey 2, possibly reflecting the tariff changes made between survey 1 and survey 2. Overall, the percentage of customers stating 'quite secure' or 'very secure' has steady reduced over the course of the surveys from 40% to 13%, noting that the financial well-being of the community is subject to several external influencing factors. These general trends of satisfaction decreasing between baseline to survey 1 and increasing to survey 2 may be due to seasonal trends, as well as the tariff adjustments made.

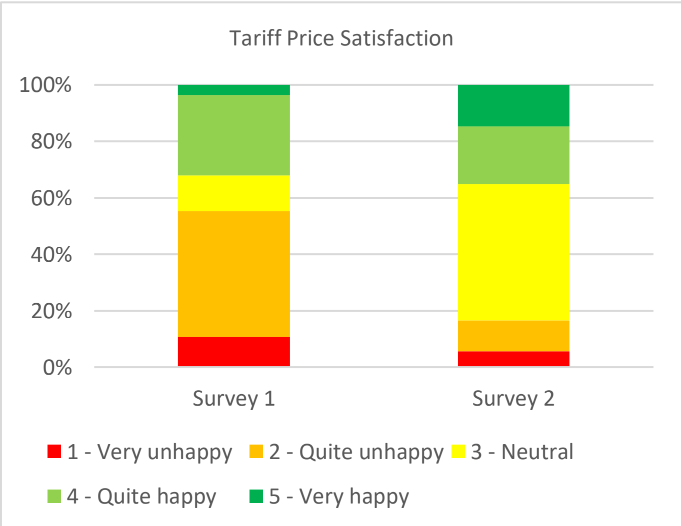
## 7.5 Female empowerment

The number of women and girls with access to electricity is 164, or 49% of all people in connected households. The number of female owned businesses is 3. The figures below show the results for the surveys on female empowerment KPIs. The data suggests positive impacts on amount of free time, independence and decision making, respect within the community and household, and security in the home. The biggest changes are seen in respect within the community and household.

*Female Empowerment KPI tracking*


## 7.6 Tariff and service

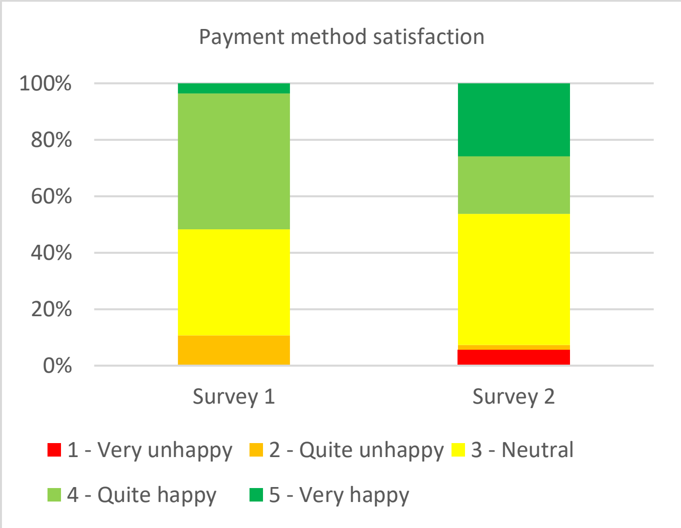
In terms of financial satisfaction with the microgrid, general satisfaction has increased from survey 1 to survey 2, reflecting the tariff reduction during this period and an associated increase in willingness to pay. Payment method satisfaction questions indicating an increase in 'very happy' from survey one to survey two, although a few customers being 'very unhappy'. According to field staff, payment through site agents has generally been a success although if top-ups are needed outside of work hours, customers suffer. This indicator informs the impact and satisfaction of new tariff payment methods such as mobile money integration.

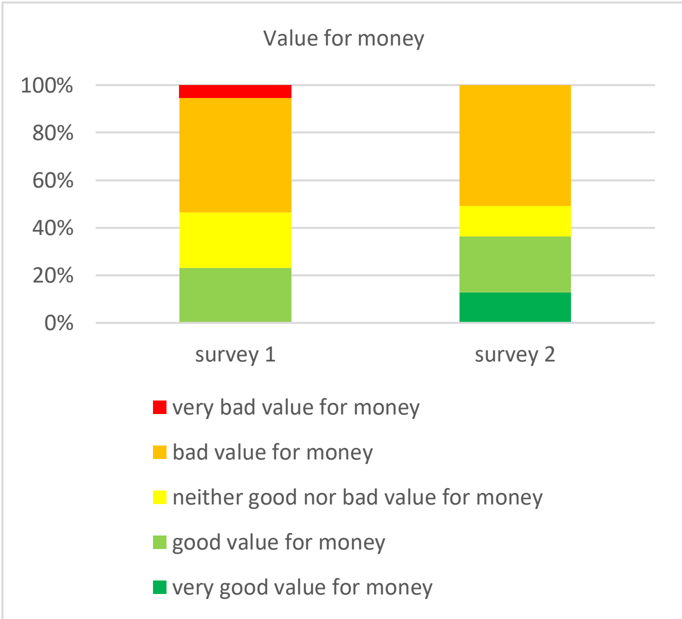


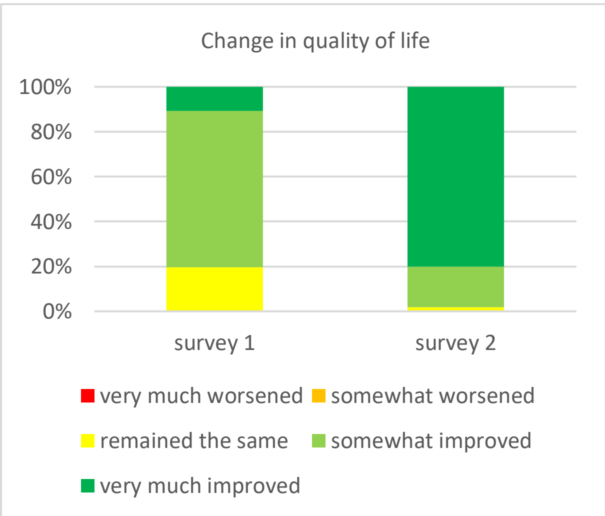
The electricity spend comparison, calculated as the average of current spend minus ideal monthly spend is 2.26 USD for survey 1 increasing slightly to 2.29 USD for survey 2, corresponding to 43% and 44% of the monthly ARPU for 2021, suggesting the customers willingness to pay is still lower than the current tariffs.

Value for money responses indicate over 50% of customers still regard the microgrid bad or very bad value for money, although some customers have begun to indicate its good or very good value by survey two. Survey 1 revealed 14 % indicating payments were ‘a burden’ and 1 customer said they were a ‘heavy burden’. By survey 2 this had reduced to 9% indicating it was ‘a burden’ and no customers reporting ‘a heavy burden’. Asking this question is checking the international development ethos of “do no harm”, as microgrid developers want to avoid pushing rural customers into deeper poverty through cost of electricity, breaking their primary social goal.

The responses to the "To what extent has the quality of life of you and your household changed since getting the connection?" shows that by Survey two, 80% of respondents stated ‘very much improved’ with a further 29% reported ‘somewhat improved’. A similar trend is seen with increased perception of safety, with over 80% indicating they feel ‘somewhat safer’ or ‘much safer’ in both surveys, with the proportion of ‘much safer’ increasing to 64% by survey two.





In terms of perception of negative consequences of the microgrid, in Survey 1, 28% of respondents indicated that there were negative consequences of the microgrid, with most comments on why this is relating to the electricity being expensive, limited number of lights, and that it does not satisfy all of the needs, and some complaints of down time. In Survey 2 this had reduced to 15%, with less mentions of expensive electricity and more complaints on the grid outages, reflecting the issues experienced with the SteamaCo meters.

# 8 Recommendations for the Malawian microgrid ecosystem

The findings and experiences of deploying solar microgrids through EASE have informed the following recommendations to increase the impact, growth and sustainability of the microgrid sector in Malawi. Recommendations are outlined below for practitioners and decision makers in policy, along with suggested research agendas to accelerate access to energy through rapid deployment and scaling of solar microgrids. All stakeholders from the public, private and third sector, as well as customers and communities need to understand the opportunities which solar microgrids present, and there is a need for improved capacity to deploy, operate and maintain microgrid technologies as well as proven business models to ensure long term sustainability.

## 8.1 For policy makers and the regulatory ecosystem

### Designate space for microgrids in rural electrification planning

Despite a draft rural electrification plan in place and the newly published Integrated Energy Plan for Malawi, uncertainty still exists regarding future plans for grid expansion, putting microgrid developers at risk of grid encroachment leading to stranded assets. This threat can be alleviated through defining geographic areas or zones that are demarcated for microgrid development, de-risking the sector and attracting more investment. Although a draft list of potential minigrid sites is available for Malawi, it was found that for some sites, distance from the national grid was not accurate (some sites were less than 5km from grid), some were not accessible during rainy season, and some of them had a very low population density and there weren't any economic activities taking place. This suggests further site prospecting work would benefit mini-grid developers.

Additional confidence can be gained through clear understanding of what happens when the grid does arrive, with procedures set in place for microgrid to grid interconnection. Central grid operators gain from additional generation and distribution grid infrastructure that have already been paid for, while further risk reduction is offered to microgrid operators.

### Implement smart subsidies to reduce tariffs and improve microgrid financials

*Inspecting PV panels at Kudembe*

The high costs, low revenue and associated vulnerabilities in matching microgrid operational expenditure with income from electricity sales demonstrates the need for smart subsidies to enable solar microgrids to scale. Subsidies for grid connected electricity supply in the Global North are universal, and expecting the poorest communities to bear the full cost burden of electrification with no support is both unstainable and unfair.

The responsibility for serving the ultra-poor has traditionally fallen to the government or non-profits (charitable) sector, and hasn't been the responsibility of the private sector. Solar microgrid developers need to be financially viable, and being asked to provide electricity to those that can't afford it compromises their sustainability. From a business point of view, microgrid developers are already struggling for unit economic viability and saddling them with additional costs will reduce their capacity to operate as a sustainable business, ultimately affecting their ability to serve customers who can afford them.

The use of smart subsidies can solve this, where the government pays microgrid developers to connect and offer a reliable electricity service to rural customers. Although mostly donor led, Cash Transfer Programmes are already being used to additionally provide improved energy services to those living in extreme poverty. In Malawi these have been for improved firewood cook stoves and pico solar products and but can also be used for microgrid connections.  Key challenges lie in identifying low income households and how to direct subsidies in a way that doesn't distort markets but offers support to balance affordable tariffs with sufficient resources to operate the microgrid sustainably, while allowing a surplus to be built up to replace components at end of life.

Through data sharing of costs and income between multiple active microgrid projects, a case can be made to government based on a quantification of the subsidy required; this should be the subject of economic modelling and further research.

### Design and operationalise a sector wide Environmental and Social Management Framework for microgrids and invest in better understanding of microgrid environmental impacts

Environmental and Social Management Plans are recognised as necessary for ensuring microgrid developers actively reduce their environmental impact and increase the social impacts of the project. However, the requirements to produce an ESMP were found to take up significant resources relative to the size of the microgrids. A proposal to reduce these overheads is the implementation of an Environmental and Social Framework for micro and mini-grids in Malawi. This policy tool would outline environmental and social requirements for a mini/microgrid operator to adhere to, with a lighter touch submission requirement of a project brief to specify any particularities unique to their project, which is already a requirement for MERA. This approach would allow microgrid developers to streamline regulatory burdens, expediting the development process.

*Distribution grid maintenance*

Although adhering to the ESMP requirements stipulated through Malawi Environmental Protection Agency (MEPA), the focus of this project has been to promote and measure social impact and propose a financially viable business model. As a result, the project's environmental impact has not been closely monitored. It should be highlighted that recycling of solar PV components is not currently accounted for in Malawi and creates a future environmental issue while acknowledging that significant development of the microgrid sector is predicted in Malawi. Investments in battery and PV recycling facilities should be made to prevent toxic waste and land contamination.

### Remove barriers from VAT and FOREX

The Government of Malawi currently offers a VAT waiver for solar PV products which is a welcome development for solar microgrid developers. Allowing this waiver to be expanded to all components associated with microgrids, including shipping containers, distribution equipment such as house wiring and overhead cables and ancillary devices, would further reduce CAPEX costs and improve financial sustainability of microgrid projects.

Significant challenges and delays were faced with lack of foreign capital to purchase components for the microgrid. This could be overcome by central banks designating a set amount or percentage of foreign capital towards renewable energy equipment, acknowledging the impact providing electricity can have on the Malawian economy. Removing barriers to purchasing microgrid components from abroad will offer further reductions to implementation delays.

### Invest in research and capacity building

There is a lack of skilled technicians, system designers and business expertise in the Malawian microgrid sector and efforts are required to address this through targeted capacity building. This can include government support for technical short courses, degrees offered through local universities, online training and internship opportunities both local and international. The government can also support private sector capacity building through business development initiatives such as tailor-made technical assistance, business incubation and acceleration programs. Capacity building can also be supported for private sector operators on access to finance through bank loans and also business planning/management skills.

The government can also accelerate microgrid deployment by investing more in microgrid research and development in partnership with the academia, for example through directly providing research funding or innovation challenges, in line with the research agenda proposed below.

## 8.2 For microgrid developers, both development partners and private sector

### Seek collaboration and partnerships with multiple development players

For sustainable and accelerated microgrid deployment collaboration is necessary across all initiatives, between community members, local NGOs, the local government, and agencies working on the project. Coordination and consolidation of donor led initiatives in the microgrid sector is needed to avoid duplication; microgrid developers should network with all levels of energy-related organisations, such as NGOs, the government, the commercial sector, and research institutes. They should also be a part of actor networks and coordinate stakeholder interactions, including networks both local (e.g. REIAMA) and international (e.g. African Mini-grids Developers Network).

### Improve financial sustainability through innovative business modelling

The key challenge currently preventing microgrids from scaling in Malawi is a proven business model with a positive cash flow. In order to address this, practitioners have two options: reducing costs or increasing demand. Suggestions for cost reductions have been given in this report and for CAPEX include bulk purchasing to achieve economies of scale. For OPEX, ongoing business modelling when operating multiple microgrid sites should prioritise efficiency in maintenance operations and fieldwork activities to minimise transport and labour costs. Demand can be promoted through giving priority to productive use anchor loads, then businesses and finally household customers. This approach will guarantee more daytime usage, reduce wasted generation and increase revenue

The motivations for implementing smaller microgrid systems was based on assumptions that lower CAPEX costs would be more likely to be paid back through tariff payments of poor rural communities. Unfortunately, the additional infrastructure of shipping containers and associated electronics has indicated that the base costs are higher, and in order to reduce the cost per connection the size of the system should be increased.

Consumers face affordability challenges, and microgrid developers need to innovate in pricing and payment methods. PAYG tariff and mobile money offer another innovation that can reduce costs, increase accountability and efficiency in payment collections. Adopting consumer financing business models for provision of appliances to customers will further foster uptake in electricity use and associated revenues for the microgrid operator.

### Invest in technological innovations

Technical innovations for solar microgrids including smart metering, data logging, remote monitoring and control need to be embraced by microgrid developers to offer efficient, technically robust and sustainable systems resulting in reliable electricity provision for their customers. Efforts should be made to explore supply chain options for such technology, as well as developing opportunities for local manufacture to increase the local value chain elements, spurring economic development.

The value of remote monitoring has been demonstrated in terms of reducing maintenance costs and providing better understanding of system performance, as well as a tool for troubleshooting and providing early warnings when issues are about to occur. As microgrid operators transition to operating a fleet of microgrids, the need for remote monitoring in parallel with robust asset management strategies becomes obvious, and should be a focus of investment in hardware and human capacity from the outset.

Similarly, the value of smart meters is clear, through remote access to customer data, remote switching and dynamic tariff changing. The technical challenges experienced with the smart meters through this project are outweighed by the benefits in terms of data and control, and in the long run are seen as an essential element of any solar microgird system.

## Understand the importance of measuring impact

Social impact measurement should be conducted to inform business strategy, but also shared with government to make better informed decisions on resource allocation and have better understanding of solar microgrid services. Socio-economic effect is a complex topic without a straightforward recipe for success. To combat poverty holistically, energy (and other) projects should span several domains, and collaborations should be actively sought to ensure successful transdisciplinary scope and long-term outcomes. To promote socio-cultural understanding and a deeper understanding of social impact, the emphasis should be on developing a collaborative community where projects can draw on the knowledge base of ongoing or completed projects and share or lend expertise or experts, including local social scientists.

## Acknowledge the value of and set aside resources for community engagement

For poor, dispersed rural communities electricity supply is often not enough. Sustainable microgrid projects must be designed to be run as businesses with livelihoods components to increase community income built in, rather than assumed to evolve from the provision of electricity. To achieve this, microgrid developers need to better appreciate and integrate the needs and capacity gaps of rural communities and be able to serve them in an efficient and impactful way. Local capacity building and community engagement thus needs to be prioritised for effective microgrid enterprises to function and grow sustainably, with a budget allocated to support these interventions. Community engagement should be a key focus embedded in the service offering of a microgrid developer, with financial and human resources set aside in the business plan to cater for these social requirements, enabling better service, happier customers, higher demand and net positive balance sheets.

## 8.3 Research agendas

Collaborating with academic and research institutions for data analysis, research and knowledge exchange allows much needed insight and understanding into microgrid performance and planning. The experiences of EASE have demonstrated the value of academic institutions partnering with in-country practitioners: in a collaborative synergy, resource constrained microgrid developers get data analysis and recommendations for improved service while researchers access primary data and a pathway to impact for their research outputs.

- **Techno-economic business modelling:** More research is required to develop and trial microgrid business models, linked with innovative financing mechanisms. As the microgrid sector transitions from single pilot projects, like those presented in this report, to scaled operations the funding must similarly change from donor funding to income from tariff sales and subsidies. Designing the most effective tariffs for different customer segments and quantifying smart subsidies needed for microgrids to be financially sustainable while offering the social impact desired by governments is a valuable and necessary research agenda to accelerate microgrid deployment.

- **Microgrid performance monitoring through data acquisition and analysis:** Efficient technical design and sustainable business models are improved with access to, and analysis of, primary data from existing microgrids. Monitoring Key Performance Indicators in technical, economic and social impact domains, and sharing this data, will aid in building the knowledgebase and accelerating the nascent microgrid sector.

- **Understanding demand:** There exists a significant gap in understanding demand of newly connected customers in Malawi. Measurement of load profiles, quantification of load growth over time and providing insight on demand patterns and seasonal trends is essential for designing cost effective and technically efficient microgrids. Measuring and sharing demand disaggregated by customer segments is especially important for informing business models and tariff setting.

- **Spatial planning:** Combining Geographical Information System (GIS) data such as population density, solar resource, and distance to maintenance centres with estimated demand and load profiles can inform spatial planning of microgrids, locating and sizing systems and optimising maintenance logistics of operating multiple sites. Such research can contribute to existing rural electrification planning currently such as the Malawi Integrated Energy Planning Tool.

*BNG Installation team commissioning PV array at Mthembanji*

- **Asset management:** Assuming the microgrid market grows and future microgrid operators will own and manage multiple microgrid sites, valuable research is needed to inform asset management strategies to sustainably manage a fleet of microgrids. Such research will predict timings for replacement components, optimise maintenance regimes, and maximise cost savings and technical efficiency through remote monitoring.

- **Distribution grid design and optimisation:** Some design tools exist to assist in planning and designing mini and microgrid distribution grids, including bespoke software developed at UoS to optimise distribution design through logic and least path fitting algorithms [16]. The development and use of such programming can aid microgrid designers and reduce costs through optimisation of resources.

- **Interconnecting microgrids:** Research on technical, business and regulatory arrangements for interconnecting the national grid with microgrid is much needed as has yet to be trialled in Malawi. Similarly, as more microgrids are installed, the opportunities for interconnecting microgrids include shared generation and storage, improved efficiencies and innovative business models which can lower tariffs and increase resilience. Little research has been done in this area and should be on the research agendas.

- **Productive Use:** identifying anchor loads that can be powered by solar microgrids, and designing integration to the microgrid systems will be a game changer for microgrid business models through fostering demand and increasing utilisation rate. In addition to technical integration of PUE appliances to match generation capabilities, business design of the PUE enterprise is needed, including exploration of value chain analysis, appliance financing and key maker models.

- **Social Impact:** Longitudinal studies of the impact of electricity with cross-disciplinary collaboration between social scientists, engineers, anthropologists and economists amongst others will inform the effectiveness and impact the microgrid has on the community it serves and shape recommendations for additional interventions to be implemented alongside providing a secure electricity connection. A general recommendation is given for social impact surveys to be conducted by microgrid practitioners to understand the impact the microgrid has on the community it serves. Existing frameworks and best practice guides [17] should be followed.

*Security light at Kudembe generation hub*

# 9 Next steps for scaling solar microgrids in Malawi with a social enterprise approach

The purpose of EASE is to promote a social enterprise approach to energy services. A social enterprise is defined as an organisation with primary social or environmental objective that trades in order to fulfil its primary mission. Building from the learnings summarised in the document, United Purpose has set up a social enterprise to own and operate microgrids in Malawi – Kuyatsa - offering a vehicle to deploy and operate microgrids efficiently and sustainably, developed as an intended output of EASE.

## 9.1 Overview of Kuyatsa

Kuyatsa is legally registered in Malawi as Company Limited by Guarantee. It has a board of directors comprising energy and business experts who are currently working for or have previously engaged with UP. As a child company of UP, Kuyatsa will receive operational and organisational support as well as financial security from the wider NGO, but will still maintain flexibility and efficiency through being an independent entity. Kuyatsa leverages significant experience from UP's Sustainable Energy Management Unit which has been active in the off-grid energy space for over 10 years and has strong relationships with key line Ministries at national and district level working towards Malawi's vision 2063. Kuyatsa management and field staff work with trusted partners to develop, install and operate solar microgrids including the following:

- BNG electrical (Lilongwe) provide MERA accredited installation and maintenance services, with extensive experience in distribution grids, solar PV generation and smart meters.
- University of Strathclyde (UK) offer partnership for data analysis, research and knowledge exchange to inform the Kuyatsa business model and wider Malawian energy ecosystem
- National, district and local governance structures are engaged and involved at all stages of development, installation and operation of the microgrids.

## 9.2 Approach and vision

Kuyatsa contributes to a vision of universal energy access in Malawi through developing and operating solar microgrids at scale. Key themes of Kuyatsa's microgrids approach include:

- ***Sustainable tariffs****:* The approach offers affordable, cost reflective tariffs that balance customer ability and willingness to pay with sufficient income to cover operation costs and replacement of components at end of life, ensuring financial sustainability.
- ***Extensive data collection and dissemination****:* We recognise the value of data in a nascent microgrid market and invest in data collection on technical, economic and social impact indicators through remote monitoring, smart meters and customer journey surveys.
- ***Strong community engagement***: Building on UP's extensive experience working with remote communities, Kuyatsa prioritises local capacity building and community engagement, in recognition of how this contributes to increased impact and financial sustainability.
- ***Stimulating productive demand****:* In order to foster increased demand for electricity and increase financial viability of microgrids, agricultural Productive Uses of Energy (PUE) are recognised as key and central to our community engagement strategies.
- ***Engagement with Ministries and regulators:*** Kuyatsa ensures that all work is carried out in accordance with relevant policies, regulations and standards. We also work to improve the sector for everyone through advocating for an enabling environment in the sustainable energy sector.

**Kuyatsa's vision is to be the leading provider of solar minigrids in Malawi, operating a national fleet of energy infrastructure by 2030**. It recognises the need for early grant funding to support pilot deployments, to facilitate the transition to other financing mechanisms such as RBF, debt and equity on its pathway to reach scale and financial sustainability.

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